Flood Risk Assessment of Chennai City – Flood Risk Model

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by

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ABSTRACT

Urban flooding has emerged as one of the maximum essential demanding situations for Indian metropolitan regions, specially for coastal towns like Chennai. Rapid urbanization, lack of herbal drainage systems, discount in inexperienced cover, and inadequately designed infrastructure have made the metropolis more and more liable to ordinary flood events. This thesis objectives to evaluate the flood chance of Chennai metropolis through growing a structured, parameter-primarily based totally Flood Risk Model that integrates chance, vulnerability, and exposure factors in accordance with globally diagnosed frameworks consisting of the ones of the IPCC and UNDRR.The look at employs a weighted multi-standards evaluation approach, assigning 40% weight to chance parameters (e.g., rainfall intensity, floor permeability, drainage coverage), 30% to vulnerability factors (e.g., inexperienced cover, casual settlements, early caution systems), and 30% to publicity indicators (e.g., populace density, financial property, slum populace). Temporal facts from 2011 to 2024, spatial GIS layers, professional authorities reports, and secondary studies shape the muse of this evaluation. Each parameter is scored and normalized to broaden composite chance maps and perceive flood-susceptible zones inside the Chennai Metropolitan Area (CMA).Key findings imply that 4 essential factors—decline in inexperienced cover, discount in floor permeability, low drainage ratio, and expanded publicity of financial property in flood zones—are the number one drivers of flood chance in Chennai. The version exhibits that even though there were slight enhancements in infrastructure and early caution systems, environmental degradation and densification maintain to boom flood publicity and impact. The flood chance rating throughout exceptional years indicates a marginal decline, suggesting incremental enhancements however now no longer sufficient to offset weather pressures and unregulated city sprawl. This thesis concludes through presenting spatially grounded and policy-related interventions focused on the recognized high-chance parameters. Additionally, the version is designed to be adaptable and scalable, permitting it to be implemented to different Indian towns with comparable flood vulnerabilities. The final results of this studies isn't only a diagnostic device however a sensible decision-guide machine which could tell city planning, zoning regulations, and catastrophe control frameworks. It emphasizes the want for integrated, facts-driven, and weather-responsive procedures to gain long-time period flood resilience.

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CHAPTER 1 – INTRODUCTION

1.1. BACKGROUND STUDY

The urban flooding has become an increasing concern in the world, particularly the cities which were enlarged in the developed rate. And as we pave over more and more land for roads, buildings and other infrastructure, the natural ability of the ground to soak up rainwater is impaired. With intense and erratic downpours — which climate change tends to worsen — it all adds up to frequent and devastating floods. Urban planning and infrastructure tend to be less advanced than the overall pace of development in many developing countries, and cities are especially vulnerable. In India, cities including Mumbai, Bengaluru, Hyderabad, Chennai had witnessed severe urban floods in the recent past. This is not only due to heavy volumes of rain but is the result of pollution and poor drainage, encroachments in water bodies, vanishing greenery and rise of the number of informal settlements on low-lying areas. Urban flooding is both a natural hazard here and a man-made crisis, the result of decades of misguided land use decisions, haphazard growth and a lack of investment in infrastructure. Chennai is a case in point. As a coastal city on the south east of India, it is naturally vulnerable to flooding during the northeast monsoon. But in recent years, the problem has deteriorated amid rapid urbanization, invasion of marshlands and lakes, substandard stormwater drains and waste management. The 2015 floods, which paralyzed much of the city, resulting in mass evacuations and economic damage, and which revealed major deficiencies in the way Chennai prepares for and responds to such disasters. And even after being subject to several infrastructure improvements and a smart city makeover, every year, it is not spared the ubiquitous seasonal flooding.One of the things that is missing in most flood studies, and much of the planning responses to floods, is a comprehensive analysis of all the factors that contribute to flood risk — not just rainfall, or drains, but population density and housing vulnerability and land use changes and proximity to water bodies. There is a wish for a holistic data-driven approach to include environmental, infrastructural and social parameters for accurate flood risk assessment and to support decision making by authorities.This research attempts to close that gap by developing a flood risk model which combines several parameters in the three dimensions of risk: hazard, vulnerability, and exposure. Applying spatial data and GIS tools, it charts flood risk in the Chennai Metropolitan Area, laying out high-risk areas that demand immediate action. The study also seeks to strengthen long-term planning by suggesting policy interventions that could make the city more resistant to inundation. It will all ultimately help bring Chennai closer to a safe, sustainable and climate-resilient future – and to synchronize with larger global goals too, such as **SDN 11 Sustainable Cities, SDN 13 Climate Action and SDN 9 Infrastructure and Innovation.**

1.2. AIM

To assess the flood risk of Chennai city through Flood Risk Model by quantifying and analyzing the Hazard, Vulnerability and Exposure parameters, and recommend policy level interventions.

1.3. OBJECTIVES

- To assess the current flooding risk scenario in Chennai and to conduct flood risk mapping and classification of risk zones.
- To identify the research gap of flood risk assessment methodology.
- To identify the key hazard, vulnerability, and exposure parameters influencing flood intensity in Chennai.
- To develop and analyze a flood risk model using selected parameters, calculate risk scores across different years, and assess opportunities for reducing risk and supporting development.
- To recommend policy-level interventions to mitigate the city's flood risk.

1.4. SCOPE OF THE STUDY

- In this study, flood risk is evaluated in the Chennai Metropolitan Area (CMA) using a parameter-based Flood Risk Model that consolidates into a weighted combination of three prominent factors: Hazard (40%), Vulnerability (30%), and Exposure (30%).
- These parameters over time and comparing them against comparable urban spaces, the model identifies the primary drivers of flood risk.
- While first built to apply to Chennai, the model could easily be tailored to Indian cities, making it a scalable and adaptable tool to manage flood risks in urban areas.
- The study contributes to the achievement of SDG 11 (Sustainable Cities), SDG 13 (Climate Action), and SDG 9 (Industry, Innovation, and Infrastructure), through a sustainable, climate-informed, and data-driven method of city planning.

1.5. LIMITATIONS

- Limited access to recent high-resolution spatial data.
- Minimal field surveys (primary data collection) for ground validation.
- Static parameter weights ignore flood variability.
- Excludes real-time rainfall and tidal data of the city.

- Needs recalibration for other city contexts.
- Ignores future land use and infrastructure change.

1.6. NEED FOR THE STUDY

- Chennai is one of the most flood-prone coastal cities in India, with significant socioeconomic and environmental impacts from frequent flooding events.
- Existing flood risk assessments often lack a holistic approach, neglecting the integration of physical and socioeconomic factors in the risk model.
- The study aims to support disaster preparedness, reduce flood related losses, and promote sustainable urban development in Chennai.

1.7. METHODOLOGY

The methodology used in the work here follows a systematic, multi-phase process that also mirrors the five central goals of the study. The process starts with Objective 1 where insights are gleaned from Phase I, including a preliminary flood event review, to identify the study area, i.e., the Chennai Metropolitan Area (CMA). Moving to Objective 2, the focus shifts to the investigation of potential research gaps within conventional flood risk analyses and consideration of appropriate tools and methods, namely spatial analysis coupled with multi-criteria decision-making methods. Objective 3 is based on a thorough review of the literature to support the identification of parameters that apply to three major elements of flood risk, which are hazard, vulnerability, and exposure. It ensures that the model covers the physical and the social-economic aspects of flooding. The parameters are then coupled into Objective 4, where a model of Flood Risk is created through spatial overlays, weightings, and normalization of data. The model is used across several time points (2011, 2015, 2020, and 2024) in order to monitor flood risk trends over time. Finally, in Objective 5, the results are interpreted by examining the risk levels to come up with results and findings, and critically evaluating the patterns that are seen, implications, and limitations. The research converges to policy recommendations towards interventions on flood mitigation, risk reduction, and climate-resilience urban planning in Chennai. The systematic methodology ensures a systematic, data-informed process of flood risk evaluation and supports evidence-based decision-making.

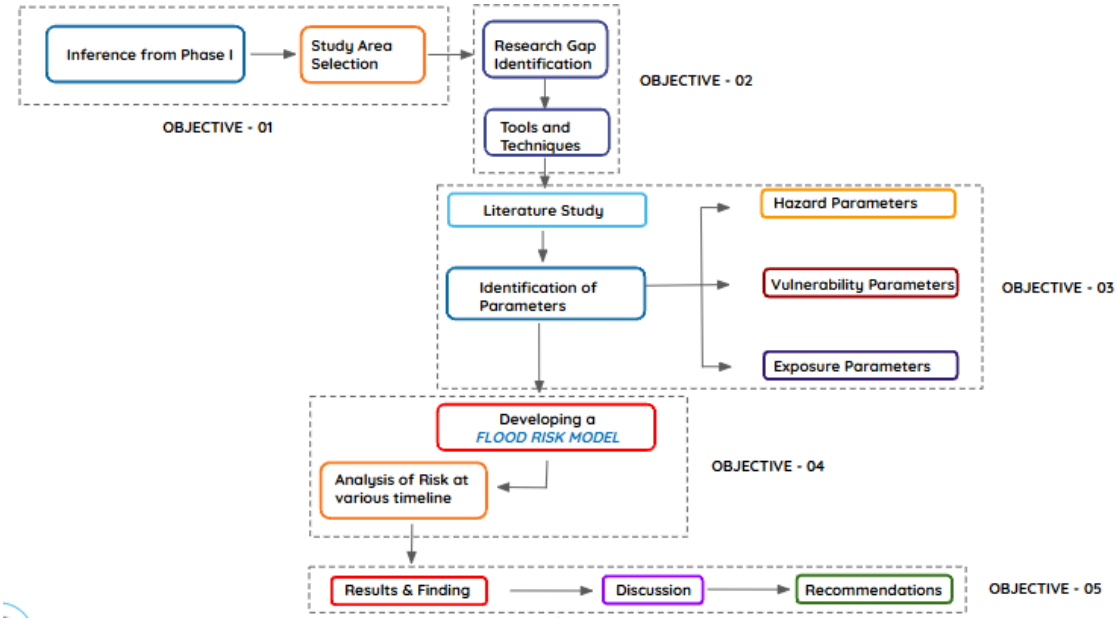

Fig 1 Methodology of the Flood Risk Assessment of Chennai City

1.8. TOOLS & TECHNIQUES

This study involves a multidisciplinary methodology that is focused primarily upon geospatial analysis, remote sensing, statistical evaluation, and multi-criteria decision-making. The utilization of the tools and methods was based on how they could process large scale spatial data, support comparisons over time, and support the integration of diverse flood-related parameters. The following tools and techniques were used across the various phases of the study:

1.8.1. GEOGRAPHICAL INFORMATION SYSTEM (GIS)

Geographic Information System (GIS) tools formed the backbone of spatial analysis in the research. QGIS 3.22 and ArcGIS 10.8 software were applied to analyze spatial data sets, create thematic layers, and carry out zonal analysis. Digitization of the drainage lines, buffer of water courses, overlay of hazard, vulnerability, and exposure factors, and zonal classification of risk areas were the major activities. GIS helped to compile a composite flood risk model from multiple data layers and facilitated spatial correlation with past flooding occurrences.

1.8.2. REMOTE SENSING AND IMAGE PROCESSING

Sentinel-2 and Landsat 5 and 8 platforms-retrieved satellite images were used to examine the dynamics of green cover and changes in land cover/land use over selected years

(2011, 2015, 2020, 2024). Remote sensing techniques were used to derive a proxy of green cover and surface permeability through the Normalized Difference Vegetation Index (NDVI). Techniques of image classification were employed to map wetlands, built-up areas, and waterbodies to facilitate flood vulnerability assessment through land transformation.

1.8.3. STATISTICAL ANALYSIS

Both basic and sophisticated statistical measures were employed to examine the correlation amongst different parameters and flood occurrence. Pearson correlation coefficient was used to measure the strength of relationship between flood-prone areas and parameters like rainfall intensity, green cover, drainage density, population density, and type of housing. Descriptive statistics were employed to compare year-wise trends and to evaluate time-varying behavior of parameters.

1.8.4. MULTI-CRITERIA DECISION ANALYSIS (MCDA)

To assign weights to various parameters objectively, the Analytic Hierarchy Process was used. The process entailed pairwise comparisons of parameters that fell under the categories hazard, vulnerability, and exposure based on experts. AHP facilitated the derivation of parameter weights that were subsequently applied in the flood risk classification through weighted overlay analysis. Consistency check was carried out to validate the judgment matrix.

1.8.5. FLOOD INUNDATION AND VALIDATION DATA

Historical flood maps of the National Remote Sensing Centre (NRSC) and the Tamil Nadu State Disaster Management Authority (TNSDMA) were employed to verify the model results. 2015, 2021, and 2023 flood extent maps were superimposed over parameter maps to see spatial correlations and to verify flood risk zones obtained through the model.

1.8.6. MICROSOFT EXCEL

Excel was used heavily to support data entry, normalization, rating, scoring, and the computation of risk index. It also facilitated tabulation of scoring thresholds and trend analysis over a range of years by parameter.

1.8.7. GOOGLE EARTH PRO

Google Earth Pro was used to validate conditions on the ground, georeferenced locations of sites, and visually cross-reference encroachments on water bodies, changes of land use, and the physical extent of informal settlements. It enabled map layer visual verification and richness in spatial perception of at-risk areas. Overall, integrating GIS, remote sensing, statistical analysis, and knowledge-based decision-making methods provided a solid basis to examine flood hazard in Chennai. These methods enabled a multi-dimensional and spatially explicit evaluation that underpins technical analysis and policy-relevant information to assist flood mitigation planning.

CHAPTER 2 – STUDY AREA PROFILE

2.1. INTRODUCTION

Chennai, the capital city of Tamil Nadu, is a major metropolitan Centre in southern India and a hub for industry, commerce, education, and governance. Over the past few decades, the city has experienced rapid urbanization and population growth, resulting in significant stress on its natural systems and urban infrastructure. Among the environmental challenges faced by Chennai, urban flooding has emerged as one of the most critical. The 2015 floods and subsequent events have highlighted the need to understand the spatial and socio-economic characteristics that influence flood vulnerability. This chapter outlines the geographic, demographic, environmental, and infrastructural features of the Chennai Metropolitan Area (CMA), which forms the core study region for flood risk analysis.

2.2. GEOGRAPHICAL AND ADMINISTRATIVE OVERVIEW

Chennai Metropolitan Area is positioned on India's southeastern coast bordering the Bay of Bengal to the east. It spans latitudes 12.9°N to 13.2°N and 80.1°E to 80.3°E and has a surface area of around 1,189 sq.km. The area has flat topography with a mean height varying between 2 and 10 meters above sea level and is, therefore, extremely prone to water stagnation and tidal backflow in cases of heavy rains. CMA is comprised of the Greater Chennai Corporation and the surrounding municipalities and panchayats that fall under the control of the Chennai Metropolitan Development Authority (CMDA). The city has 15 administrative zones and 200 wards that are used primarily as the spatial units of urban planning and service provision. The planning area covers the core city plus around it is the rapidly urbanizing peri-urban settlements. Three prominent rivers, namely Coovum, Adyar, and Kosasthalaiyar, pass through the city, along with several man-made canals like the Buckingham Canal that historically provided the city's drainage backbone. These natural and man-made systems once used to moderate the floods but are nowadays often breached by encroachment and pollution.

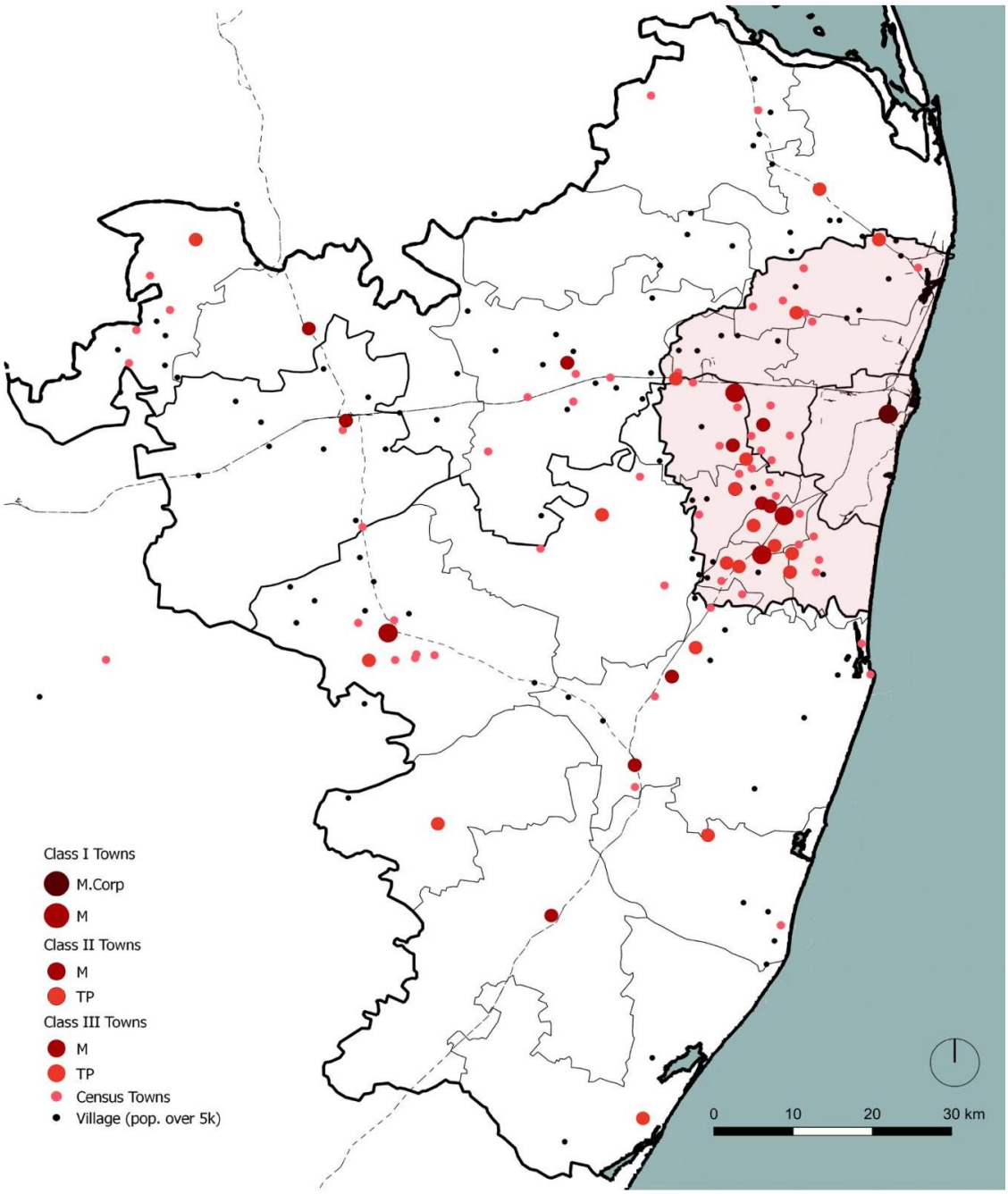

Figure 1 Administrative Map - Chennai City

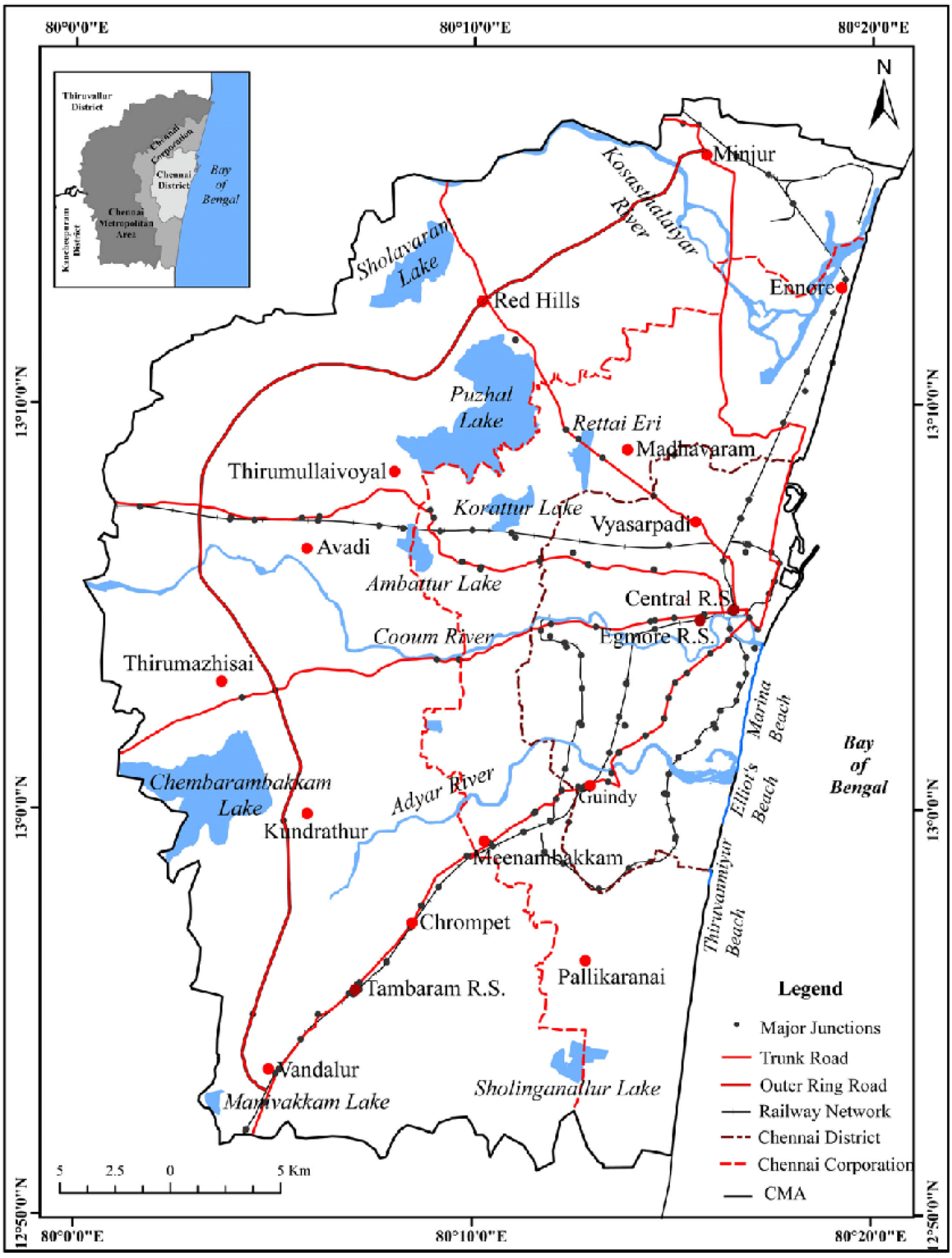

Figure 2 Geographic Map - Chennai City

2.2.1. URBANISATION OF CHENNAI CITY

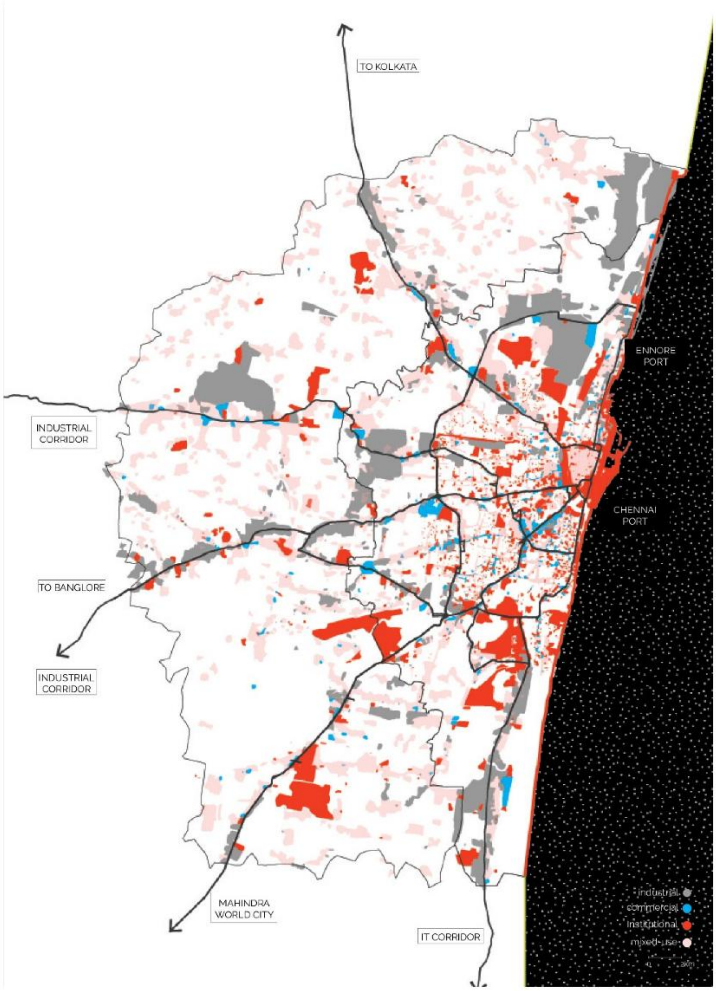

Figure 3 Urban Growth of Chennai City

Chennai, the capital of Tamil Nadu, has also developed extensively and rapidly in recent decades from its original form as a colonial port city to become one of the major metropolitan cities in India. Growth in industry, infrastructure development, and population influx of people for work in industries such as information technology, manufacturing, and business have facilitated urban expansion of the city. Chennai's developed part has expanded significantly, particularly along roads such as the Old Mahabalipuram Road (OMR), Grand Southern Trunk Road (GST), and Outer Ring Road (ORR), ever since the 1990s. The development has also involved conversion of open spaces, wetlands, and agricultural lands for residential, commercial, and industrial use. Even though urbanisation has helped the economy to grow and improve accessibility to facilities, environmental degradation, traffic congestion, and overburdened infrastructure have also followed. The development in this way, especially in the peri-urban zones, in the absence of proper planning and fragmentation, has increased the city's exposure to

possible menaces like urban floods, and thus the necessity of integrated, resilient, and sustainable urban planning to save the city is of utmost importance.

2.2.2. URBAN SPRAWL OF CHENNAI CITY

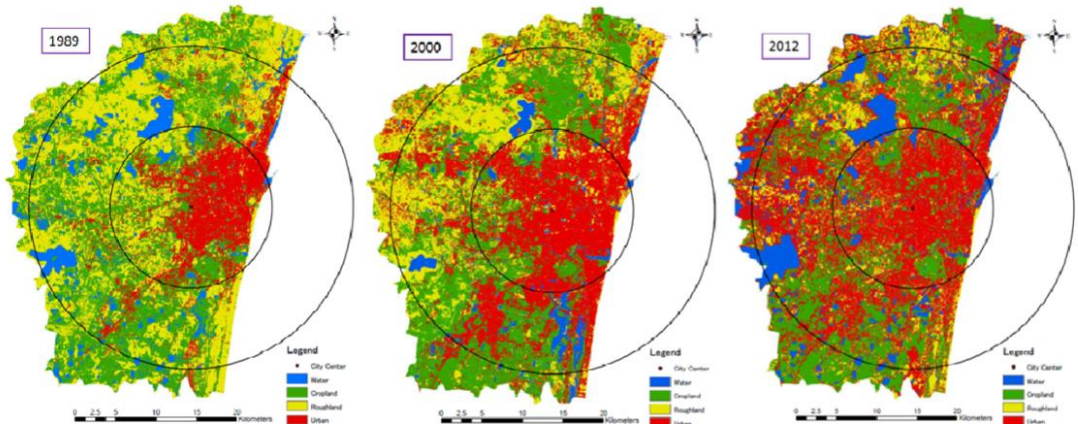

Figure 4 Urban Sprawl throughout years (1989,2000,2012)

Urban sprawl describes the unplanned outward spread of cities into their outskirts, typically marked by low-density housing and commercial zones. Chennai, one of India's rapidly expanding metros, is a prime example of this phenomenon, driven by economic, social, and infrastructural changes. To tackle urban expansion and growing flood threats, it's essential to understand how Chennai's sprawl has evolved, its current trends, and what factors are fueling it. Chennai's early urban development was centered around historic neighborhoods like George Town, Triplicane, Egmore, and Mylapore. However, the 1990s ushered in a wave of economic liberalization and industrial growth that triggered widespread expansion. The city's footprint began stretching southward along Old Mahabalipuram Road (OMR), southwest via GST Road, and westward toward Sriperumbudur and Poonamallee. Over time, farmland, wetlands, and peri-urban open spaces were transformed into residential colonies, business zones, and industrial parks. By 2024, Chennai's urban spread continues unabated—particularly across its southern, southwestern, and western fringes. Major development hubs include the OMR IT corridor, the GST industrial zone, and the Outer Ring Road (ORR) belt. Satellite imagery reveals substantial urban growth in areas like Sholinganallur, Pallikaranai, Tambaram, Perumbakkam, Avadi, and Sriperumbudur. This rapid development has dramatically shrunk green spaces, wetlands, and farmlands, undermining environmental resilience and natural water drainage

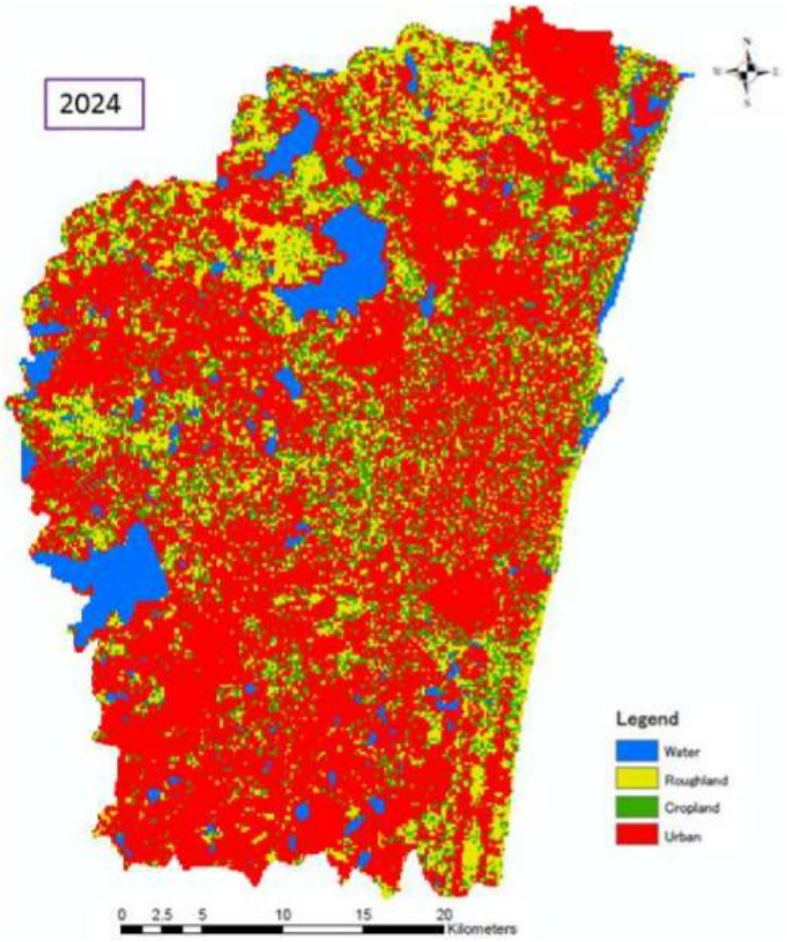

Figure 5 Urban Spral (2024)

Several overlapping factors contribute to Chennai's relentless outward growth:

Economic Factors: The rise of IT parks, Special Economic Zones (SEZs), and industrial hubs attracted large-scale migration, spurring demand for housing and infrastructure in peripheral areas. **Population Growth**: A rising population, driven by rural-urban migration, created intense housing demand that pushed new development beyond city limits. **Infrastructure Expansion**: Improved roadways, expressways, rail lines, metro routes, and ring roads enhanced connectivity, making previously distant areas more accessible and attractive to investors. **Real Estate Surge**: Relatively low land prices on the city's fringes attracted real estate developers, fueling the rise of expansive residential and commercial complexes. **Weak Urban Regulation**: Poor enforcement of zoning laws, fragmented governance, and delays in urban planning have allowed unchecked and scattered growth.

Consequences of Urban Sprawl

Environmental Loss: Wetlands and green buffers that naturally mitigated floods have been lost, leaving the city more vulnerable. **Strained Infrastructure**: Many newly

developed peripheral areas lack essential services like drainage, water supply, sewage systems, and transportation links—intensifying flood risk. **Widening Inequality**: Uneven distribution of infrastructure and services has led to greater socio-economic disparities, especially affecting low-income communities in fringe areas. **Rising Flood Risk**: The increase in paved surfaces and poor drainage planning in newly urbanized zones has heightened the city's susceptibility to flooding, as seen in frequent waterlogging in these suburbs.Chennai's unchecked sprawl demands immediate, coordinated action from urban planners and policymakers. Sustainable growth must be prioritized through better governance, stricter land-use regulation, and integrated flood-mitigation strategies. Only with a proactive, well-regulated approach can the city curb environmental damage and ensure a more resilient urban future.

2.3. DEMOGRAPHY

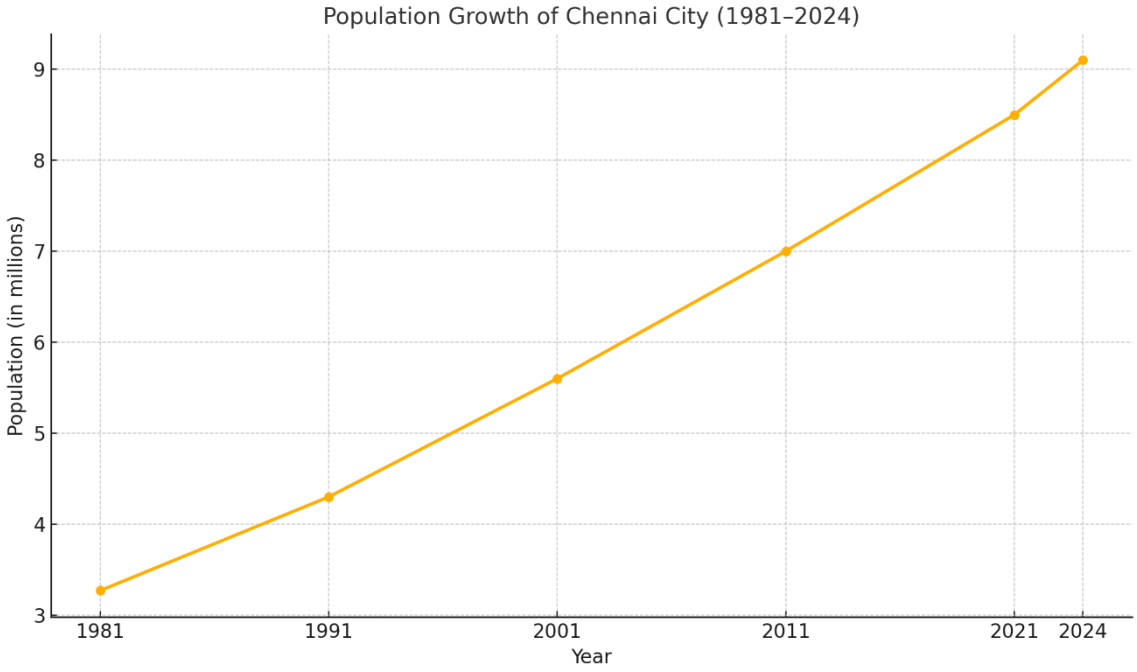

Figure 6 Graph of Population growth of Chennai City

Chennai is one of India's most densely populated metropolitan cities, with a population of approximately **4.68 million** within city limits and over **10 million** in the larger Chennai Metropolitan Area (CMA), as per the **2011 Census**. The population density in core city zones exceeds **25,000 persons per sq.km**, reflecting intense urban pressure. Chennai's demographic profile is shaped by high levels of **rural-to-urban migration**, driven by employment opportunities in the industrial, IT, and service sectors. A significant portion of the population lives in **informal settlements and slum clusters**, with nearly **28% of households** categorized under slum dwellers by the Tamil Nadu Slum Clearance Board (TNSCB). These communities are often situated in low-lying, poorly

drained areas, increasing their vulnerability to urban floods. The city's **age structure** is relatively young, and the literacy rate is high, but socio-economic disparities persist across wards and zones, particularly in access to housing, sanitation, and healthcare. As urbanisation continues, Chennai's demographic dynamics pose both opportunities for economic growth and challenges for inclusive, resilient, and equitable urban development.

2.4. SOCIO – ECONOMIC CONDITION OF CHENNAI

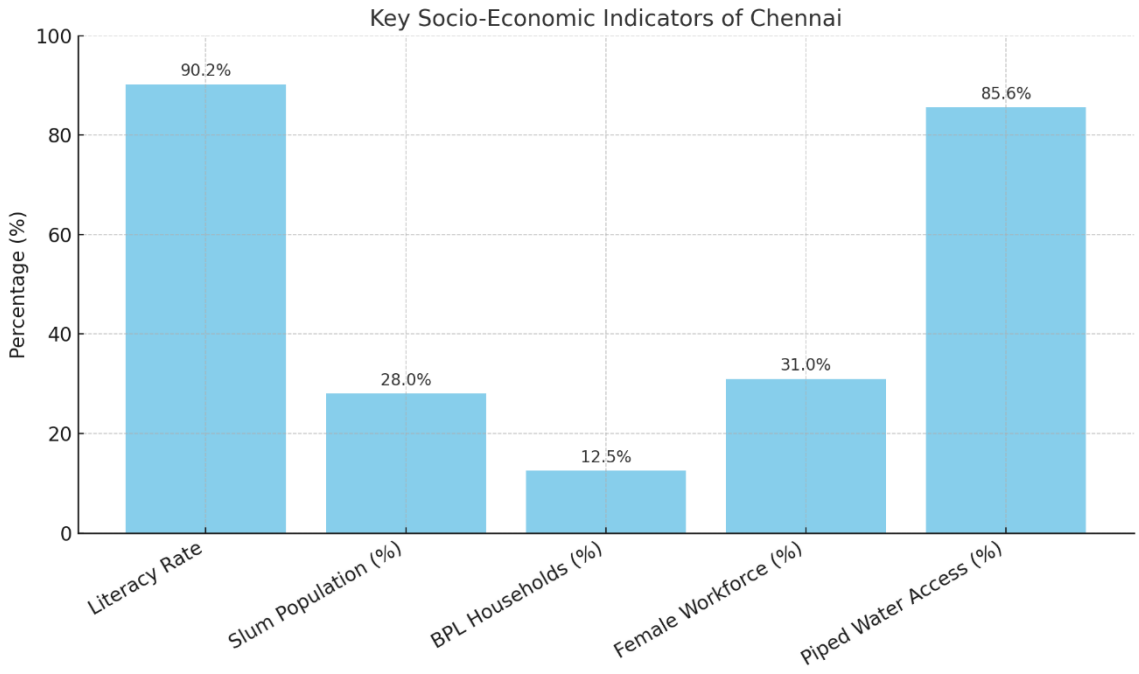

Figure 7 Socio Economic Indicators of Chennai City

Chennai, one of India's most vibrant metropolitan centres, presents a deeply layered socio-economic landscape shaped by waves of migration, expanding city boundaries, and stark infrastructure gaps. Despite notable progress in public services, education, and urban infrastructure, large portions of the city's population continue to grapple with vulnerabilities that leave them especially exposed to urban challenges like flooding. With a literacy rate of 90.2%, Chennai surpasses the national urban average, nurturing a skilled workforce that has helped build thriving sectors such as information technology, finance, and education. However, this progress is uneven. Only about 31% of women participate in the workforce, pointing to systemic barriers that restrict their access to jobs, limit mobility, and undermine financial independence. This gender gap also weakens the ability of households to prepare for or recover from crises like floods, where adaptive decision-making is crucial. Even as the city grows economically, about 12.5% of families still live below the poverty line. According to the Tamil Nadu Slum

Clearance Board, nearly 28% of residents live in formal and informal slum settlements. These neighbourhoods are often found in low-lying, flood-prone zones—along riverbanks, canals, or marshlands. Residents here face serious risks due to substandard housing, insecure land tenure, and lack of reliable sanitation, drainage, and healthcare. These conditions make them especially vulnerable when disasters strike. Infrastructure coverage in core city areas is relatively strong—over 85% of households have piped water access, and most central neighbourhoods are connected to sewage systems. Yet, this isn't the case citywide. Rapidly growing suburban and peri-urban areas often lack the infrastructure needed to support their expanding populations. These service gaps become critical during storms or cyclones, triggering health emergencies, particularly in slums and resettlement zones. Inequality in Chennai is not just economic—it's geographic. Well-established localities like T. Nagar, Adyar, and Anna Nagar enjoy better infrastructure, public transport, and economic opportunity. On the outskirts, areas like Sholinganallur, Avadi, and Pallikaranai are marked by informal construction, weak public services, and fragile ecosystems. This spatial imbalance hampers fair and efficient disaster planning, especially when it comes to flood preparedness and response. Poverty, insecure housing, and patchy service delivery combine to create pockets of extreme flood vulnerability. Communities with limited financial resources, little institutional support, and inadequate public infrastructure are least able to withstand or bounce back from flooding. That's why detailed socio-economic assessments are key not just for identifying who is at risk, but for ensuring that flood management strategies are truly inclusive and effective.

2.5. TOPOGRAPHY & DRAIN SYSTEM OF CHENNAI

The topography of Chennai is generally flat and lowland, and thus, the city is naturally susceptible to water stagnation during rains. The city slopes from west to east in a gentle manner, draining away gradually towards the Bay of Bengal. This natural slope gets regularly disrupted by encroachments, poor infrastructure, and haphazard constructions. The general terrain of most city zones is 2 to 10 meters above mean sea level, with many of the zones in north and central Chennai falling below the mean sea level or on the tidal line of back flow, which renders them highly flood-prone. Natural drainage of Chennai was formerly reliant on a well-linked network of rivers, canals, and wetlands such as the rivers Cooum, Adyar, and Kosasthalaiyar, the Buckingham Canal, as well as many man-made tanks and marshlands. These traditionally served as buffer zones, soaking up and draining away excess rainwater. The network, however, has in recent years suffered hugely from urban expansion, dumping of solid waste, as well as the encroachment and salination of water channels. The renowned Pallikaranai Marshland, which used to serve as the sponge of the city's south, has significantly shrunk and has been encroached upon.The stormwater drainage system, intended to complement natural runoff, is unevenly distributed and is usually short of capacity.

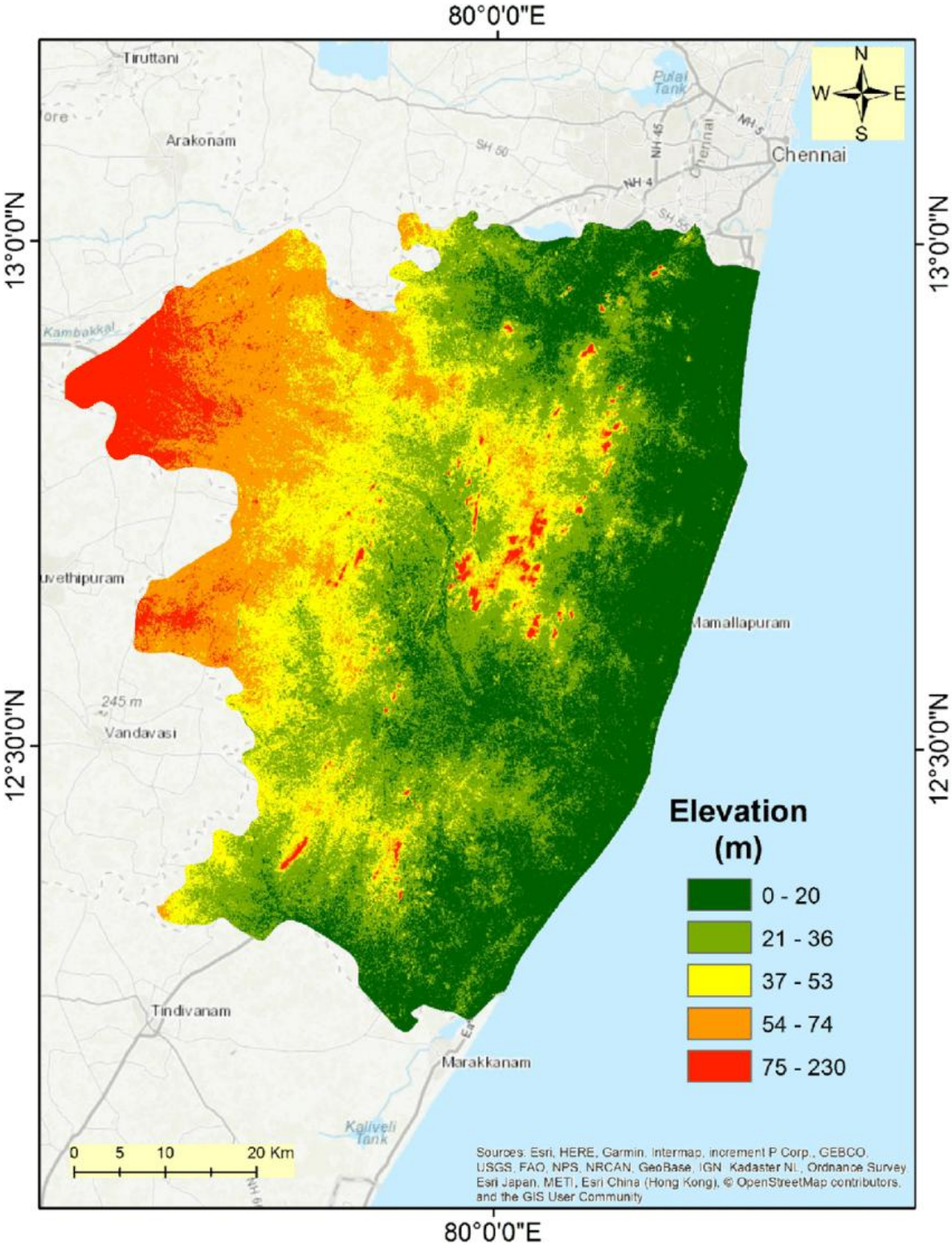

Figure 8 Elevation Map of Chennai

Many central zones are served with stormwater drains, but peripheral zones have none, while many of them have disconnected portions of drains which block during heavy rains. Drain inlets are often blocked by improper solid waste management and

deposition of silts, diminishing the ability of drains to accommodate flow during the monsoons. On the occurrence of cyclonic storms or cloudburst, the city's level terrain and delayed runoffs cause extensive waterlogging, which tends to overwhelm natural as well as artificial drainage channels. In recent years, the Integrated Stormwater Drain Project (ISWD) has been implemented to upgrade and increase the drainage infrastructure, but its implementation is patchy and confined to chosen areas. With this, the rehabilitation of natural drainage channels, conservation of wetlands already in place, and enhancement of the urban stormwater system remain paramount to the climate preparedness and flood resilience of Chennai.

2.6. CLIMATE AND RAINFALL PATTERN

Chennai, located along the southeastern coast line of India bordering the Bay of Bengal, experiences tropical wet and dry climate type according to Köppen (Aw). The climate of Chennai is characterized by high temperatures, sea-borne humidity, and episodic rainfall, all of which are primary factors making it susceptible to flood threat.The climatic condition in Chennai is mostly warm and humid in all seasons, with average daily temperatures between 25°C and 42°C. Summer, especially from April to June, is extremely hot, with temperatures frequently exceeding 40°C. Being a coastal city, Chennai has high humidity levels in all seasons, with relative humidity usually between 60% and 90%, especially during monsoon seasons. This constant humidity not only influences human comfort but also leads to extended durations of drying spells and waterlogging after floods, especially in slum pockets and low-lying and drained areas.Unlike most of the other main Indian cities that are typically reliant on the June-to-September Southwest Monsoon, Chennai is specifically reliant on the October-to-December Northeast Monsoon. About 60% to 70% of the city's total annual rainfall is achieved in this brief span of time. Though the Southwest Monsoon does occur, its contribution to the city's total rainfall is very small. Chennai gets an average of 1,200 mm to 1,400 mm of rainfall annually, although actual annual figures do vary as the city is susceptible to cyclonic systems and climate variability. Severe Precipitation Events Chennai is increasingly experiencing short-duration and heavy rain events. For instance, in the catastrophic floods of December 2015, Chennai recorded over 300 mm rainfall in 24 hours, leading to extensive urban flooding, displacement, and infrastructure damage. Excessive rainfall was also experienced during Cyclone Nivar (2020) and Cyclone Michaung (2023), which indicate a rising trend of more severe and more frequent extreme weather conditions. These disorganized trends strain the city's stormwater infrastructure and have a tendency to overburden natural drainage processes. The metropolitan region is situated close to the eastern seaboard and is most exposed to Bay of Bengal tropical cyclones. Cyclones such as Vardah (2016) and Nivar (2020) have introduced high-speed winds, heavy rain, and high storm surges. Not only do these cyclones create instantaneous flooding into the city, but they also cause persistent disruption to livelihood, mobility, and basic services. Climate models predict increasing intensity and

variability of such storms, which can be explained by high sea surface temperatures and the more general effects of global climate change.

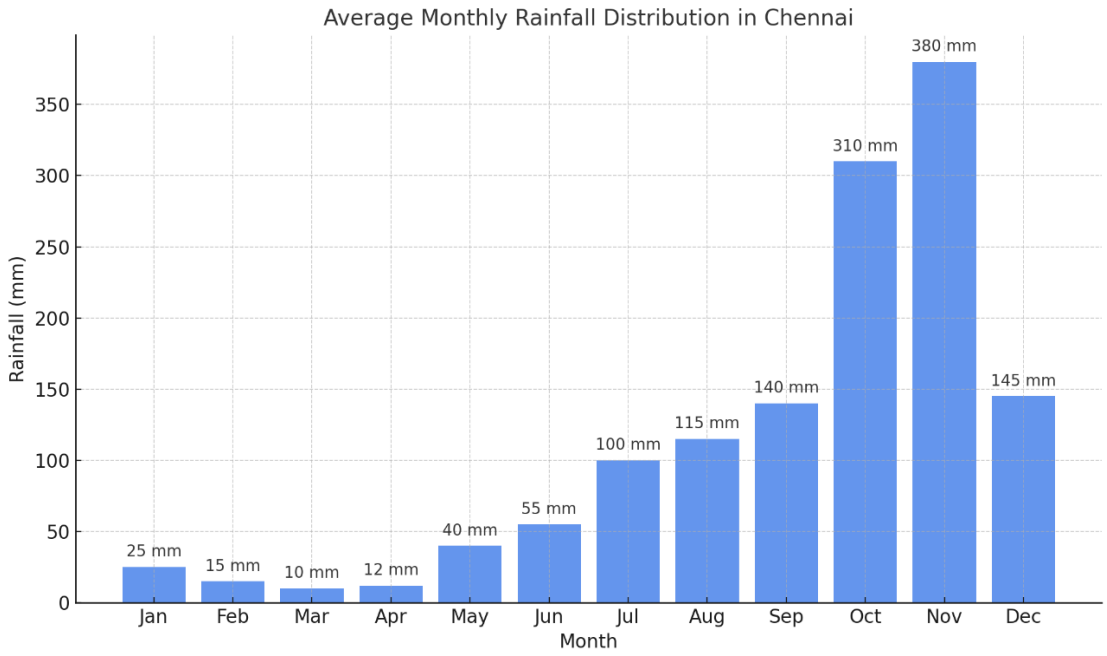

Figure 9 Avg. Monthly Rainfall

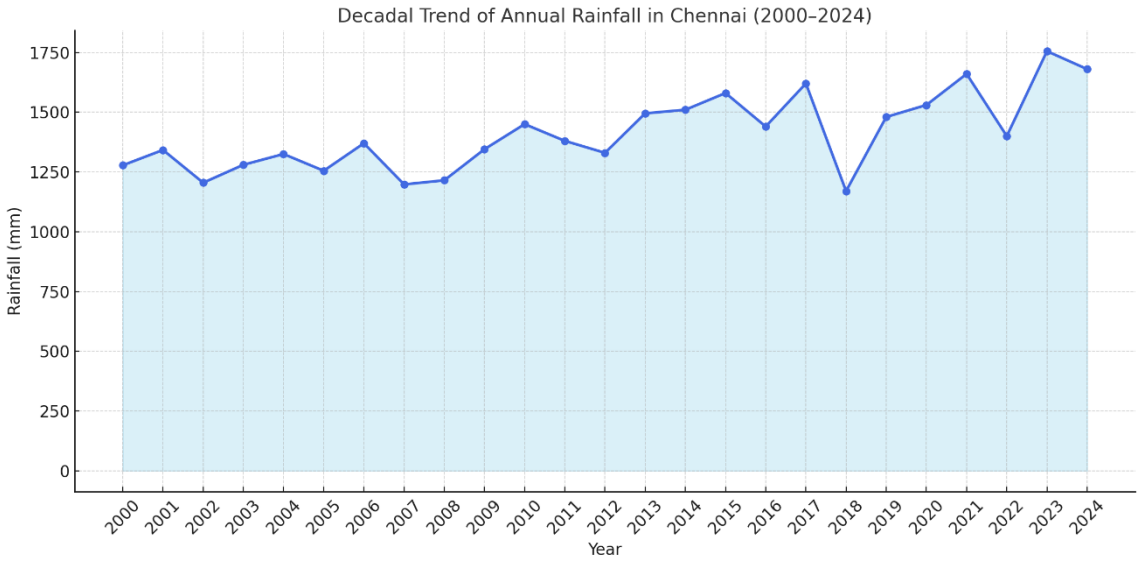

Figure 10 Annual Rainfall for past 2 decades

Emerging Risks and Trends Over the past two decades, the variability and intensity of rain in Chennai have shown greater unpredictability, which reflects broader climatic changes in the area. Episodes of moderate, evenly spread rainfall have reduced, while sudden events similar to cloudbursts have increased. This changing form of rain,

combined with random urban development and the destruction of wetlands, significantly increases the vulnerability of the city to flooding, especially in low-lying and flat regions where the drainage of water is slow.

2.7. LAND-USE & LAND COVER (LULC)

The urban landscape of Chennai has undergone drastic changes in the last two decades, with urbanization at a fast pace bringing about widespread changes in land use and land cover. Historically, the region was marked by a diverse cover of wetlands, cultivation plots, and open green areas that served as natural catchments for stormwater run-off. But with the pace of economic development, along with population growth and uncontrolled growth, has resulted in massive tracts of these lands being replaced with impermeable surfaces. Satellite images and remote sensing studies show a significant increase in the built-up area of Chennai—from a relatively small part of the city in the early 1990s to largely covering the city landscape in 2024. At the same time, the crucial ecological elements like wetlands, lakes, and open spaces have seen a significant reduction or became fragmented, thus impairing the natural rainwater-absorption and drainage capacity.

The LULC transformation is most evident along the major transport corridors and the urban fringe, where industrial parks, housing, and commercial centers extend into agricultural lands and natural habitats. The transformation not only enhanced surface run-off during intense rainfalls but also worsened the city's micro-climate by preventing evapotranspiration and augmenting the urban heat island effect. Dense built-up and low vegetation cover zones are therefore increasingly prone to waterlogging and flooding. Comprehending these LULC processes is important, as they provide the foundation for efficient flood risk modelling and sustainable urban planning. Through the use of multi-temporal satellite data, the research identifies key hotspots where land conversion has severely undermined natural flood attenuation mechanisms. This data are utilized to inform urban resilience planning, highlighting the importance of maintaining existing greenspaces, rehabilitating degraded wetlands, and developing land use policies that consider development within environmental sustainability.

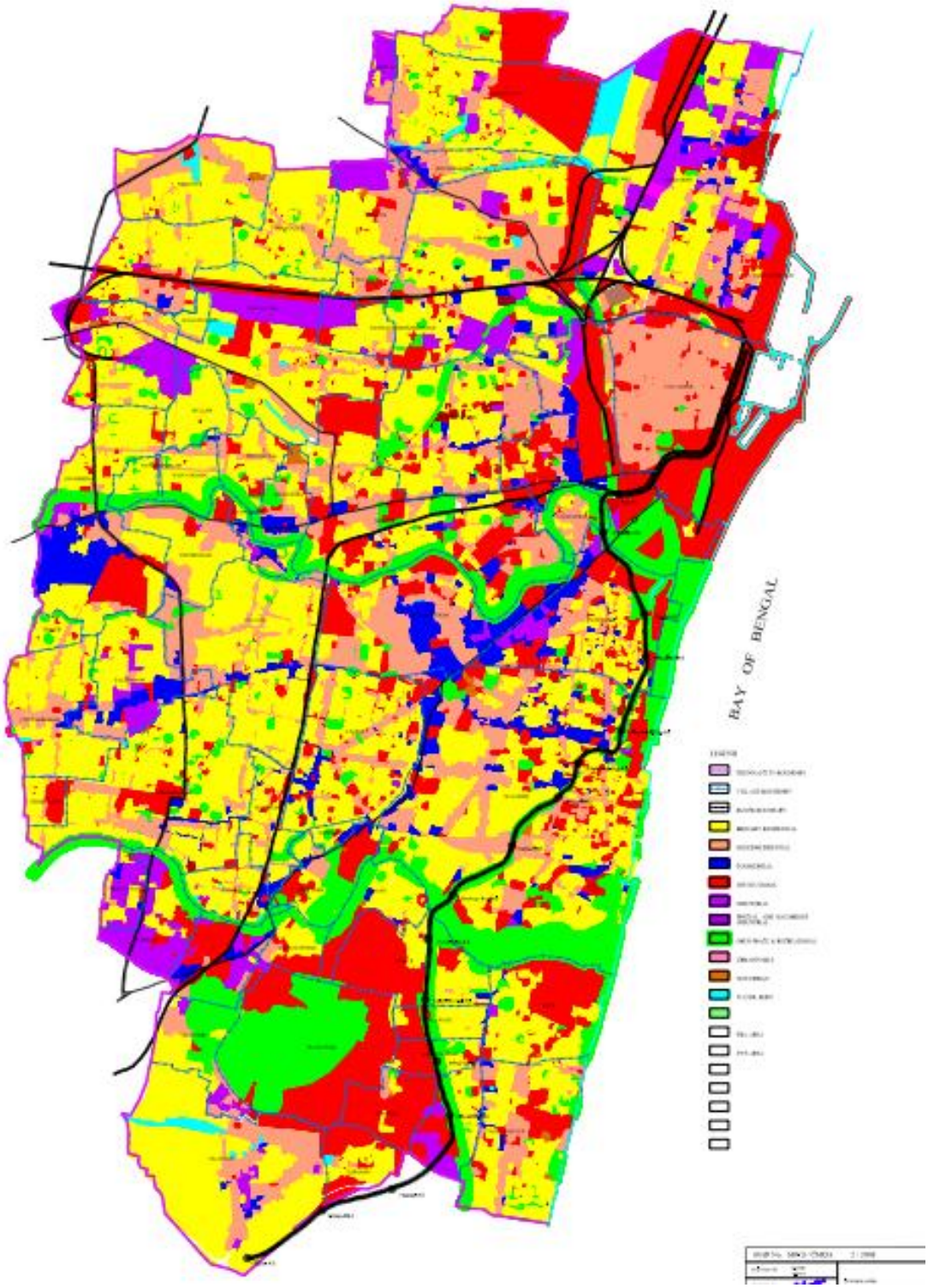

Figure 11 Proposed Land use 2026

2.8. INFRASTRUCTURE & SERVICES

2.8.1. PHYSICAL INFRASTRUCTURE

Chennai's physical infrastructure has grown rapidly to support its growing urban population. The city has a well-developed road network, including arterial roads, national highways, and local roads; however, several roads suffer from encroachments and lack of drainage facilities. Most roadways during the monsoon season often become impassable due to inefficient stormwater management practices. While there is a stormwater drainage system in the inner areas, it remains undersized, segregated, or choked with solid waste. Moreover, newly developed peripheral areas under the jurisdiction of the Chennai Corporation often lack basic stormwater management facilities. While the electrical and telecommunication network is extensive, it is prone to being disrupted during extreme weather, especially in flood-prone locations. While Chennai has built a rail and metro transit system improving mobility, its integration with disaster preparedness efforts is limited. The sewerage and water supply systems, under the jurisdiction of the Chennai Metropolitan Water Supply and Sewerage Board (CMWSSB), serve most of the population; however, coverage and quality decline in peripheral areas and in slums.

2.8.2. SOCIAL INFRASTRUCTURE

Chennai has a comparatively large number of social infrastructure like education facilities, health facilities, and community centers. The city is endowed with well-developed government and private schools, colleges, and universities, mostly in the central and southern corridors. However, in peri-urban and poorer sections of society, the presence of quality education is still lacking. The health infrastructure includes well-known government hospitals (e.g., Rajiv Gandhi Government General Hospital and Stanley Medical College) and other private clinics. While most have access to tertiary care, primary health centers (PHCs) in poor and suburban areas remain poorly equipped. Community infrastructure like Anganwadi’s, marriage halls, public libraries, and crematoriums are present but in most instances, it does not include flood-resistant architecture. Under exceptional rainfall or flooding, a huge majority of such social facilities become non-functional or act as emergency shelters without planning.

2.8.3. OTHER URBAN SERVICES

Core urban services such as solid waste collection, streets lighting, public transport, and emergency response systems are integral to the day-to-day functioning of the city of Chennai. Solid waste management remains a problem, especially in slum areas where waste tends to clog stormwater drainage. Initiatives such as source segregation and GPS

garbage collection have been implemented by the Greater Chennai Corporation, but the success thereof varies highly across wards. Public transport in the form of buses, suburban rail, and the Chennai Metro continues to facilitate mobility but with frequent interruptions during the occurrence of floods. Emergency facilities such as fire stations and disaster response units exist within the city but need better coordination with local governments in the occurrence of flooding. Moreover, digital governance initiatives like GCC Smart City and flood alert systems are in the process of being developed; these need greater outreach among citizens and provision of multilingual access to make them absolutely inclusive.

Zone / Area	Key Flood Issues	Storm-water Drainage	Road Infra-structure	Health Facili-ties	Emer-gency Access	Re-marks
North Chennai (Tondi-arpet, Roya-puram)	High waterlog-ging, low ele-vation	Inadequate / clogged drains	Narrow roads, poor surfacing	PHCs pre-sent, over-crowded	Poor con-nectivity during floods	Densely built; slum concen-tration high
Central Chennai (Eg-more, Choolai)	Short-duration flash floods	Partially covered	Encroachments block runoff	Good ac-cess to hospitals	Moderate	Older drains not up-graded
South Chennai (Vela-chery, Pallika-ranai)	Wetland loss, stagnant water	Expanding but frag-mented	ORR/OMR roads flood-prone	Few PHCs, private clinics dominate	Metro/bus accessible, limited shelters	Rapid ur-banisa-tion near marshes
West Chennai (Porur, Viru-gam-bak-kam)	Drainage over-flow, upstream runoff	Missing tertiary drain seg-ments	Roads act as barriers to run-off	Suburban hospitals few & dis-tant	Incomplete link roads	Heavy residen-tial con-version of former fields
Perungu di – Sholin-ganallur Corri-dor	Tech corridor, poor resilience	Very lim-ited in new layouts	Low-lying tech parks poorly drained	Corporate clinics, no public PHCs	IT hubs have pri-vate transit only	Un-planned layouts, real es-tate-driven develop-ment

Ennore-Manali Industrial Belt	Water + industrial runoff	Minimal coverage, often blocked	Damaged during monsoons	Occupational health services only	Vulnerable to chemical flood hazards	Low-lying, surrounded by backwaters and drains

Table 1 Infrastructure Gaps

CHAPTER 3 – FLOODS IN CHENNAI

3.1. HISTORICAL FLOOD EVENTS

The history of Chennai city is marked by a number of big flood events, the majority of which have been caused by excessive monsoonal rains, cyclonic storms, inadequate urban drainage systems, and aquatic natural ecosystem encroachment. Although flooding has always been an integral part of the environmental process of the city, frequency, magnitude, and impacts of these floods have significantly increased over the past decades because of unchecked urban expansion and environmental deterioration.

Year	Event	Causes	Key Impact
1943	Monsoon flooding	Long-duration rain and poor drainage facilities	A first-reported case of urban flooding
2005	Intense Northeast Monsoon	Sudden cloudbursts, clogged drainage systems	Widespread water accumulation, power supply disruptions
2008	Cyclone Nisha	Around 300 mm of rain in 24 hours	More than 20 deaths and extensive flooding in poor city slums
2010	Monsoonal flooding	Wetland degradation, drainage system clogging with sediments	Displacement in Pallikaranai and Velachery
2015	Worst in 100 years	1218 mm in Nov-Dec, 490 mm in 24 hrs	More than 400 deaths, ₹20,000+ Cr in damages, airport shutdown
2017	Cyclone Ockhi	Heavy rainfall with slow drainage	Urban flooding in South Chennai
2018–2019	Urban flooding incidents	Failure of infrastructure and collapse of drainage system	Daily life significantly affected for a few days during short spells
2020	Cyclone Nivar	Heavy rain at night	Evacuations in flood-prone areas, damage to crops
2023	Cyclone Michaung	~250–300 mm in 12 hrs, tidal backflow	IT corridor, MRTS routes, hospitals inundated

Table 2 Historic Flood Events of Chennai

Aspect	2005	2015	2023	Inference
Physical Changes	Urban area: 278 sq. km.	Urban area: 426 sq. km.	Urban area: 489 sq. km.	Wetland loss and unplanned urban expansion exacerbated flood impacts.
	Wetlands: 84 sq. km.	Wetlands: 39 sq. km.	Wetlands: 28 sq. km.	
Physical Infrastructure	Stormwater drains: 720 km	Stormwater drains: 850 km	Stormwater drains: 1020 km	Increased drains but poor maintenance reduced efficiency until recent upgrades.
	Drain efficiency: 65%	Drain efficiency: 55%	Drain efficiency: 70%	
Social Infrastructure	Relief centers: 40	Relief centers: 85	Relief centers: 120	Gradual improvement in relief measures post-disasters.
	Capacity: 20,000 people	Capacity: 45,000 people	Capacity: 60,000 people	
Socio-Economic	Loss: ₹3,000 crore	Loss: ₹14,000 crore	Loss: ₹9,000 crore	Increasing urban population and assets raise flood risks, despite mitigation measures.
	Affected: 600,000 people	Affected: 1.8 million people	Affected: 1.2 million people	
Environment & Ecology	Trees lost: 12,000	Trees lost: 25,000	Trees lost: 9,000	Better restoration and clean-up initiatives after 2015 but insufficient ecological preservation.
	Rivers choked by 45%	Rivers choked by 60%	Rivers choked by 55%	
Governance & Institutions	Flood management plans: Basic	Flood management plans: Updated	Flood management plans: Advanced	Significant improvements in governance and policy but require sustained implementation.
	Coordination: Poor	Coordination: Moderate	Coordination: Good	

Table 3 Major historic events - Chennai City

3.2. NATURAL & ANTHROPOGENIC CAUSES

The recurrent flooding in Chennai is the final results of a synergistic courting among herbal hydrometeorological phenomena and human-precipitated modifications within-side the it prone, the volume and frequency of flooding were considerably multiplied on account of uncontrolled, rapid city increase and terrible control of infrastructure.

3.2.1. NATURAL CAUSES

Monsoon Rainfall Patterns: Chennai receives most of its rainfall during the Northeast Monsoon, lasting from October to December. Short but heavy rainfalls, sometimes exceeding 300 mm in a 24-hour duration, overwhelm both natural drainage pathways and engineered structures.

Uniform Terrain and Minimal Altitude: Most of the city is between 2–10 meters above sea level and consists of a sequence of areas near or below sea level. The very slight eastward gradient has little natural runoff, particularly at tidal backflow or high sea level.

Coastal and Cyclonic Influence: The metropolitan region is highly susceptible to Bay of Bengal cyclonic disturbances such as Cyclones Nisha (2008), Vardah (2016), Nivar (2020), and Michaung (2023), which are likely to induce severe rainfall, storm surges, and intensified flood events.

Tidal Backflow and Sea-Level Rise: Storm surges and high tides cause backflow in the Buckingham Canal and river mouths and thus reduce the ability of the city to drain surplus rainwater effectively, especially in the low-lying coastal areas.

3.2.2. ANTHROPOGENIC CAUSES

Intrusion into Natural Drainage Systems: Over the years, wetlands, reservoirs, and floodplains of rivers — represented by Pallikaranai Marsh, Korattur Lake, and the Cooum River floodplain have suffered massive loss due to urbanization and the spread of illegal housing.

Reduction of Porous Surfaces: Urbanization has resulted in the substitution of vegetative cover and open ground with hard, impervious surfaces

of concrete, which promotes surface runoff and inhibits groundwater recharge.

Poor Solid Waste Management: Stacking garbage bins in storm drains, canals, and riverbeds clogs the way for water, particularly in slums where the garbage collection is not regular. This aggravates the flash flood conditions even with moderate rains.

Under-capacitated Drainage Infrastructure: The drainage system of the city, particularly peripheral and old cities, is under-designed, outdated, or insufficient. Added areas usually do not have tertiary drains, and even the drains that exist become silted up or clogged most of the times.

Land Use Change and Regulatory Offenses: Hasty growth in water bodies and floodplains—largely in contravention of CRZ or environmental regulations—has altered natural water courses. Most IT parks, shopping malls, and gated communities are on reclaimed marshland or tank beds.

3.3. VULNERABLE AREAS & HOTSPOTS

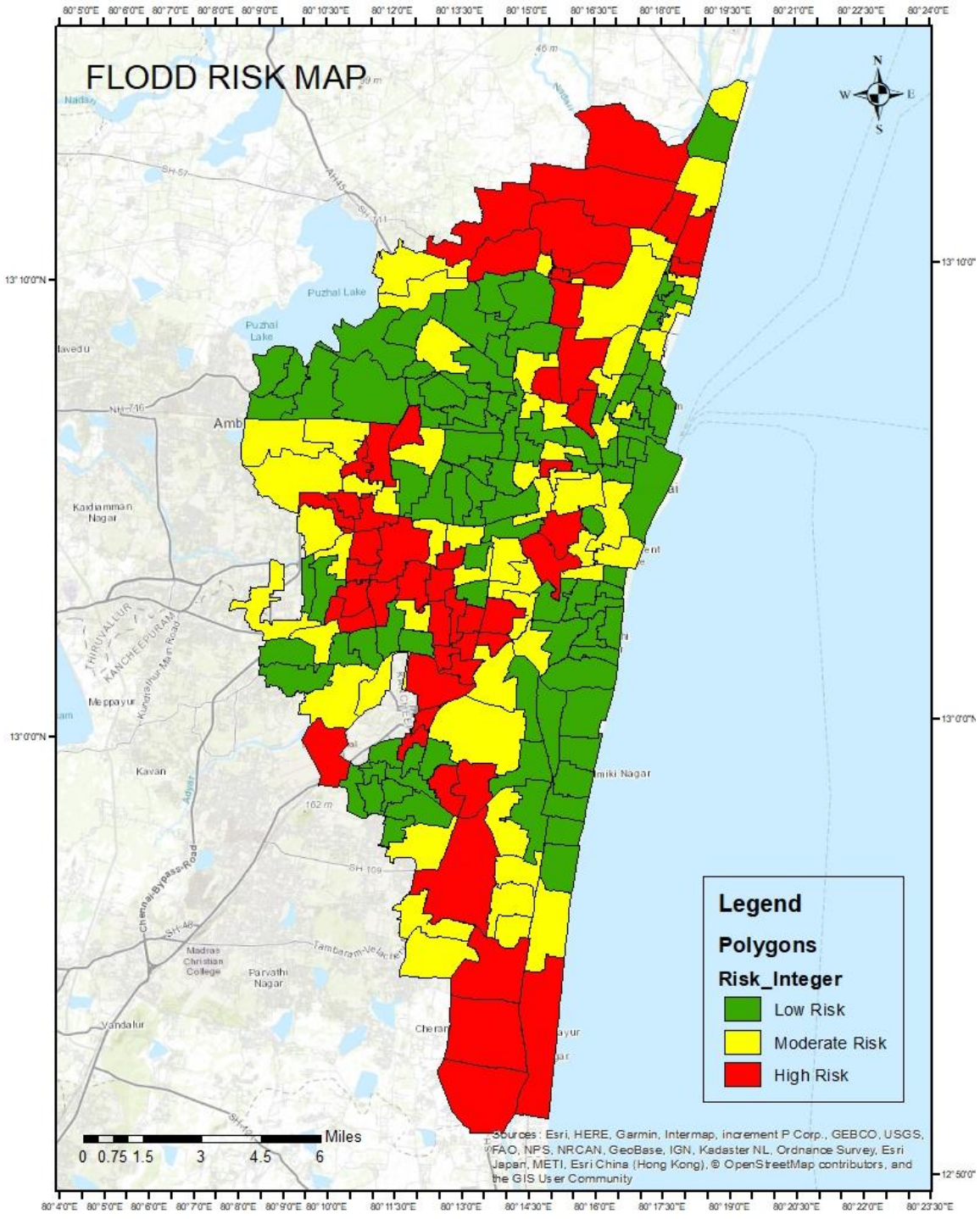

Figure 12 Flood Risk Map

The vulnerability of Chennai to urban flooding is not evenly spread throughout the city; some areas are consistently more impacted based on a mix of topographic disadvantage, poor infrastructure, encroachments, and socioeconomic weakness. Those vulnerable

areas, which tend to overlap with high-density low-income settlements and low-lying areas, get repeatedly inundated by even small rain events.

Typical Features of These Hotspots:

- Depressed or flat topography with slow runoff
- Encroachment into stormwater drains, canals, or tanks
- High density of low-income or informal dwellings
- Poor health and emergency response infrastructure
- Proximity to clogged waterways or bridges with reduced capacity
- Significance for Flood Risk Modeling

Both Vulnerability and Exposure factors of the flood risk model rate these areas high because they are densely populated, lack adequate infrastructure, and ecologically mismanaged. Prioritization of investments in flood mitigation can be facilitated by mapping and responding to these hotspots.

Area / Zone	Reason for Vulnerability
Tondiarpet, Royapuram	Low elevation, old stormwater systems, dense slum clusters
Saidapet, Mambalam	High population density, encroached canals, aging infrastructure
Velachery	Reclaimed from marshland, flat terrain, poor stormwater outflow
Pallikaranai Marsh Region	Rapid urbanisation over wetland, lack of proper drains, loss of natural absorption
Perambur, Kolathur	Drain overflow, road depression, poor garbage clearance
Koyambedu	Located at a confluence of canals, major market area worsens solid waste blocking
Perungudi, Sholinganallur	Tech parks built on lake beds, impermeable surfaces, insufficient drainage in newer layouts
Korattur and Villivakkam	Downstream zones with catchment overflow, prone to backflow from Cooum river
Ennore – Manali	Industrial discharge, tidal flooding, backwater encroachment in vulnerable fishing communities
Mudichur, Tambaram	Floodplain of Adyar River, outer zones added to GCC, lagging infrastructure

Table 4 Flood Hotspots of Chennai

3.4. INSTITUTIONAL RESPONCES & MEASURES

Flood management in Chennai entails a multi-level institutional structure that cuts across urban administration, disaster response, infrastructure, and environmental protection. Over the decades, and especially after the catastrophic floods of 2015, numerous structural and non-structural efforts have been made to enhance the city's flood resilience. Yet, problems in coordination, planning, and long-term execution continue to be seen.The Greater Chennai Corporation (GCC) is at the forefront of ensuring the stormwater drain systems of the city function properly, keeping roads in good condition, and controlling the dumping of solid waste—a factor that affects the city severely given that blockage of drains substantially amplifies the impact of floods. The Chennai Metropolitan Development Authority (CMDA) oversees urban zoning, land use planning, and areas that are prone to flooding. The Tamil Nadu State Disaster Management Authority (TNSDMA) is responsible for disaster readiness and early warning systems at community levels, and Public Works Department (PWD) and Water Resources Department (WRD) are in charge of desilting canals and rivers, embankment repairs, and renovation of traditional water bodies.Structural interventions wise, Chennai has seen an enormous scale-up of stormwater infrastructure after 2015, with over ₹3,000 crore spent on drain capacity enhancement and network expansion in flood-prone areas. Some of the major projects include Integrated Stormwater Drain Systems (ISWD) under ADB and World Bank financing, particularly for the Kosasthalaiyar and Kovalam basins. Restoration of big tanks such as Villivakkam Lake and Retteri Lake under Smart City and AMRUT programmes has also picked up. In addition, elevated flyovers and culverts have been built in perennially waterlogged areas like MKB Nagar and North Chennai to allow the flow of floodwater and rapid access during emergencies.

Non-structural measures have also picked up momentum. Among the most prominent is the Chennai Flood Early Warning System (FEWS), jointly designed with IIT Madras, which relies on sensors and real-time data to forecast rainfall and flood danger. Community disaster preparedness training projects launched by TNSDMA have been implemented to create awareness and preparedness at the ward level, particularly in vulnerable slums. Concurrently, flood zoning regulations and encroachment clearance initiatives, particularly near the Adyar, Cooum, and Buckingham Canal, are facilitating the redevelopment of natural drainage corridors.Institutional limitations, however, still plague the efforts. Fragmented effort and redundant responsibilities arise from the absence of coordination across critical departments—GCC, PWD, WRD, CMDA. The added CMA areas beyond 2011 still lack adequate coverage in stormwater and sanitation infrastructure. Additionally, inter-agency data-sharing is low, impacting planned integration and decision-making. Finally, unlike other Indian cities like Bengaluru or Surat, Chennai has no planned urban resilience or climate adaptation strategy addressing long-term flood danger comprehensively.In conclusion, though Chennai has made considerable progress in managing its flood vulnerability, there is a need for a more

integrated, data-guided, and community-led approach to institutionalize resilience and also ensure that infrastructure development is aligned with environmental sustainability.

3.5. IMPACTS AND LONG-TERM CONCERNS

Chennai floods have long-term implications beyond occasional waterlogging. Its effects are multifaceted, impacting not just physical infrastructure but also the social, economic, environmental, and public health systems of the city. Year after year, frequent floods—particularly in 2005, 2015, and 2023—have revealed underlying vulnerabilities in the urban system, emphasizing the necessity of long-term, systemic interventions. Its most immediate consequence is the disruption of daily life. roads become inaccessible, public transport grinds to a halt, and vital services like electricity, drinking water, and sewage work are brought down to their knees under the weight. During the 2015 floods, Chennai saw its international airport shut down, mass hospital evacuations, and full-blown failures of communication networks. Slum colonies and informal settlements, being along water courses and flood plains, get affected the most by such tragedies, resulting in displacement, loss of property, and livelihood—frequently in the absence of formal compensation or insurance coverage. The economic cost of flooding is staggering. The 2015 flood alone caused losses of over ₹20,000 crore, affecting industries, IT parks, and MSMEs. Business continuity in Chennai's IT corridor and port-linked manufacturing zones is increasingly at risk, impacting investor confidence and urban productivity. In addition, repeated floods have long-term effects on housing markets, real estate values, and insurance premiums, particularly in flood-prone zones such as Velachery, Pallikaranai, and North Chennai. Environmentally, floods also hasten the destruction of wetlands, tanks, and river habitats. Floodwaters polluted with solid waste, untreated sewage, and chemical contaminants from industrial areas such as Manali and Ennore also present grave threats to groundwater quality, soil health, and biodiversity. Encroachments on marshlands and development over natural drains further exacerbate the ecological imbalance. Public health issues are another critical long-term impact. Post-flood seasons usually experience outbreaks of water and vector-borne diseases like cholera, dengue, and leptospirosis. Prolonged health problems are experienced by the vulnerable population, particularly children, the elderly, and low-income groups, owing to contact with contaminated water, a damaged healthcare system, and poor post-disaster sanitation. On a larger urban level, sea-level rise and climate change are expected to worsen the flood threat in Chennai. With an increasing intensity of rainfall events and tidal surges predicted by projections, the long-term resilience of the city is threatened. The absence of a holistic urban flood management policy, along with the pace of wetland restoration and infrastructure adjustment remaining slow, continues to be a major issue for the people as well as planners.In short, the effects of flooding in Chennai are systemic and cyclical, where each event reinforces existing urban vulnerabilities. Fixing these requires not only reactive upgrades to infrastructure,

but a long-term vision that brings together environmental stewardship, social equity, and climate resilience.

3.6. MAP BASED GIS DATA

GIS software facilitates spatial analysis and visualization of flood-related risks, at-risk populations, and environmental degradation. For the flood-prone city of Chennai, this research exploits various thematic GIS layers that have been available for use and classified into flooding & hydrology, socio-economic & infrastructure, and environmental layers. While these data are precious for model construction, they also identify some essential challenges and systemic loopholes in urban flood management.

3.6.1. FLOOD & HYDROLOGY

Flood and hydrological layers outline the city's physical susceptibility and drainage inefficiencies. Flood Inundation Maps indicate that low-lying zones such as Velachery, T. Nagar, and North Chennai consistently flood even during moderate rainfall because of poor drainage and absence of retention ponds. **Issue: Unavailability of real-time flood data and low spatial resolution of historical flood layers make precise mapping difficult.** Stormwater Drain Maps depict fragmented networks, particularly in newly consolidated CMA zones such as Ambattur and Sholinganallur, where infrastructure is in the process of development. **Issue: There is no centralized GIS inventory of functional and non-functional drains; most maps fail to show illegal encroachments obstructing drain courses.**Rivers and Canals Layers demonstrate natural drainage systems heavily impaired. The Adyar and Cooum rivers have become constricted by construction and dumping of solid waste. **Issue: Siltation and absence of desilting schedules aren't updated geospatially; buffer zone demarcation of canals is missing in planning layers.**Topographic Maps (DEM) reveal poor gradient in core city areas (2–6m elevation), rendering gravity-based drainage inefficient. **Issue: Public access high-resolution DEMs (1m) are unavailable, resulting in reliance on coarse ASTER/SRTM data.**Tidal Backflow Risk Zones indicate encroachment in estuarine areas (e.g., Ennore, Thiruvanmiyur). Issue: No evident CRZ-layer integration with flood maps to spatially enforce coastal regulation norms.

3.6.2. SOCIO-ECONOMIC AND INFRASTRUCTURE MAPS

These maps represent human exposure and key service vulnerability to flood risk. Population Density Maps show highly populated wards (e.g., Royapuram, Tondiarpet) with very little open area for percolation of water. **Issue**: **Census counts are dated (2011) and do not account for accelerated post-2015 densification, especially in peri-**

urban CMA localities. Slum Settlement Maps locate high-risk informal settlements adjacent to canals and tanks. **Issue: Official slum limits usually ignore non-notified or migratory settlements, downplaying risk.** Public Transport Maps expose essential metro stations (e.g., Nanganallur, Saidapet) located in flood basins, with few alternative evacuation paths. **Issue: Flood modeling isn't incorporated into transport planning; there is no flood-safe route analysis**. Health and Emergency Services Maps reveal that most flood relief centers have either no proximity to high-risk zones or are inaccessible during floods. **Issue**: Accessibility and service gap layers are not available in official datasets; most hospitals have no flood-resistant backup systems.

3.6.3. ENVIRONMENTAL MAPS

Environmental data depicts the declining resilience of the city against flooding. LULC Maps reveal a radical transformation of marshes and tanks into urbanized land—e.g., Pallikaranai Marsh lost more than 60% since 1991**. Issue: Satellite-derived maps of LULC frequently misclassify seasonal wetlands as barren land because of dry-season imagery.** Green Cover Maps indicate precipitous loss of tree cover in areas such as K.K. Nagar, Perungudi, and Ashok Nagar. **Issue: There is no tree inventory GIS; local replantation activities are seldom geospatially mapped or monitored.**Wetland Encroachment Maps indicate legal and illegal constructions on floodplains—e.g., Retteri and Korattur Lakes experience buffer violations. **Issue: Master Plan land use layers do not include eco-sensitive buffer guidelines or wetland ecosystem services.** Soil Permeability/Runoff Index Maps show high runoff where there are large areas of asphalt and concrete surfaces. **Issue: The potential for urban runoff is not included in real estate zoning or road design decisions.** Landfill & Dumping Sites Maps reveal sites such as Perungudi and Kodungaiyur leaching into stormwater systems. **Issue: Lack of spatial observation of leachate movement or live pollution notification within landfill buffer areas.** The integration of such GIS maps not only improves spatial risk modeling but also reveals institutional blind spots and planning gaps. The absence of real-time, high-resolution, and interoperable GIS datasets remains a limiting factor for flood risk governance in Chennai. Filling in these gaps through open-data platforms, regular updates, and inter-agency coordination is crucial for evidence-based decision-making and climate-resilient urban planning.

3.6.4. FLOOD INUNDATION MAP

As the final step in this research, a Flood Inundation Map was created through GIS analysis, hydrological data, and past flood records. The map depicts the spatial area of flood-prone areas within the Chennai Metropolitan Area and explicitly marks areas of recurring water stagnation, low-lying terrain, and poor drainage connectivity. The overlap of urban areas, water bodies, and flooded zones assists in locating hotspots of high

concern, especially in North Chennai, Velachery, Pallikaranai, and the IT Corridor. The map is not just validating the results from the flood risk model but also acts as a decision-support tool for planners and emergency response teams. By integrating layers such as elevation, land use, drainage, and slum settlements, the map offers a holistic representation of Chennai's flood vulnerability and supports the formulation of resilient land use policies and targeted mitigation strategies.

3.7. NON-SPATIAL DATA

3.7.1. GOVERNMENT REPORTS & OFFICIAL REPORTS

A wide range of government-published documents and administrative records were reviewed to obtain reliable and up-to-date information on Chennai's flood exposure, urban infrastructure, and development patterns. These included policy documents from the Chennai Metropolitan Development Authority (CMDA), Greater Chennai Corporation (GCC), and the Tamil Nadu State Disaster Management Authority (TNSDMA). Yearly reports, planning reports (e.g., the Second and Draft Third Master Plan), reports of flood mitigation projects, and disaster response guides gave useful background on past trends in floods, capacity of the infrastructure, and policy structures. Further information were obtained from the Public Works Department (PWD) for drainage infrastructure information, the Tamil Nadu Slum Clearance Board (TNSCB) for data on informal housing, and the Chennai Metropolitan Water Supply and Sewerage Board (CMWSSB) for water and sanitation-related vulnerability indicators. Budget statements, urban health profiles, and Smart City implementation dashboards were also used to assess current flood mitigation efforts and public service coverage.

3.7.2. ACADEMIC RESEARCH & CASE STUDIES

To further consolidate the analytical framework and place Chennai in context with wider urban resilience literature, a variety of academic sources were referenced. Peer-reviewed journal articles, urban studies papers, and institution research reports offered detailed analysis of urban flooding, socio-spatial vulnerability, and climate adaptation. Case studies of similar Indian cities (e.g., Mumbai, Kolkata, Surat) and global examples (e.g., Rotterdam, Singapore) were examined to identify best practices in green infrastructure planning and flood risk reduction. Local university theses and dissertations, particularly from Anna University and IIT Madras, provided site-specific information and previous flood modeling exercises carried out in Chennai. Reports from think tanks like NIUA, IIHS, and CPR, UN agencies, and international databases (e.g., UNDRR, World Bank Open Data) provided international perspective and benchmarking data pertinent to flood risk assessment and urban planning.

CHAPTER 4 – DATA ANALYSIS

A multi-dimensional assessment was carried out to understand the spatial and systemic contributors to urban flood vulnerability in Chennai. This involved analyzing both physical infrastructure-related layers and social infrastructure attributes, using geospatial tools, secondary data, and institutional inputs. The findings reveal spatial patterns, structural gaps, and socio-economic inequalities that intensify the city's flood risk profile.

4.1. PHYSICAL INFRASTRUCTURE

Land Use and Land Cover (LULC): Land use analysis identified a remarkable growth of built-up area, mostly along the urban edges like Sholinganallur, Velachery, and Ambattur. Wetlands and once-agricultural land have transformed into residential and commercial areas, decreasing surface permeability and enhancing runoff. The loss of open spaces has also decreased the city's natural stormwater retention capacity.

Decline of Green Cover: Green canopy cover analysis, utilizing NDVI and satellite images, revealed massive loss of urban greenery, especially in central areas such as Teynampet, Nungambakkam, and Perambur. The growth of hard surfaces has led to the urban heat island and reduced infiltration capacity, intensifying storm waterlogging.

Drainage Infrastructure: Stormwater drain GIS layers uncover the disparity in network coverage, with inner Chennai fairly well-networked, and newly amalgamated areas such as Madhavaram and Tiruvottiyur having underdeveloped or non-continuous drain sections. Most drains are silted, encroached, or in a neglected condition, particularly in poorer areas.

Waterways and Canals: Hydrological maps of rivers and canals (Cooum, Adyar, Kosasthalaiyar, and Buckingham Canal) indicate diminished flow capacity caused by narrowing, illegal development, and encroachment. Several feeder canals are blocked or cut off from the main drainage system, affecting stormwater discharge efficiency.

Encroachments and Drainage Blocks: Satellite overlays and field mapping validate extensive encroachment on waterbodies and natural drains, particularly along Pallikaranai, Villivakkam, and Korattur lakes. These cloggings make water to be held up in urban areas, amplifying flood impact intensity.

Solid Waste Management Issues: Garbage collection data overlay with stormwater maps reveals hotspots where solid waste clogs drain inlets, especially in market zones (e.g., Koyambedu) and slums. Mismanagement of waste directly causes flash floods by lowering the effective capacity of drains.

Wetland Fragmentation : Wetlands such as Pallikaranai Marsh, Velachery Lake, and Retteri Lake have suffered drastic reduction due to real estate encroachments and

uncontrolled development. Loss of wetlands has eliminated natural buffers, causing more surface runoff and less groundwater recharge.

4.2. SOCIAL INFRASTRUCTURE

Population Density and Urban Pressure: North and Central Chennai (e.g., Mylapore, Royapuram, and Egmore) are the most densely populated, with densities of more than 25,000 persons per sq.km based on census and ward-level data. These are the worst-affected by congestion in urban areas and civic services that are overwhelmed, constraining adaptive capacity during flood occurrences.

Housing and Slum Settlements:GIS data from TNSCB reveals that approximately 28% of Chennai's population lives in slums or informal settlements. These are typically located along riverbanks, low-lying areas, and canal edges, where flooding is frequent and evacuation is difficult. Poor housing quality and lack of tenure security add to long-term vulnerability.

Informal Settlements and Exposure: Non-notified slums, usually excluded from official disaster planning, have high flood hazard exposure. These areas frequently have no access to paved roads, sanitary sewage, and medical facilities. The encroachments by these settlements onto lakes and drains cause localized flooding and create complexities in post-flood recovery.

Economic and Critical Assets: Mapping of transport hubs, schools, hospitals, and markets indicates that many key infrastructures are located in flood-affected areas. For example, metro stations such as Saidapet and Thirumangalam and healthcare centers in North Chennai are recurrently impacted by flood-induced disturbances, affecting emergency response capability.

The overlap of inadequately planned physical infrastructure with highly populated, under-serviced human settlements presents a sophisticated risk profile in Chennai. The evidence uncovers not only vulnerability, but also the uneven distribution of risk, with poor neighborhoods repeatedly demonstrating high exposure and low resilience. These revelations feed directly into spatial flood risk modeling and inform policy recommendations around infrastructure upgrade, wetland revitalization, and equitable urban planning.

4.3. SPATIAL AND TEMPORAL ANALYSIS OF FLOOD RISK ANALYSIS

Chennai flood risk is the result of numerous spatially varying and temporally changing parameters that overlap over the physical, socio-economic, and environmental spaces. This research carried out a spatial and temporal examination of specific flood risk indicators to facilitate a sophisticated understanding of how flood risk develops over time and changes between varying zones in the city.

4.3.1. SPATIAL ANALYSIS

Using GIS-based mapping techniques, key flood-related parameters were visualized and assessed across Chennai's administrative wards and extended CMA boundaries. The spatial distribution of physical indicators such as low-lying elevation, land use change, green cover loss, drainage network gaps, and encroachment on water bodies highlighted several critical flood-prone clusters. Areas such as Pallikaranai, Velachery, North Chennai, Sholinganallur, and Kolathur exhibited consistently high risk due to the convergence of impermeable surfaces, wetland fragmentation, and poor stormwater infrastructure.At the social and infrastructural indicator level, geographic overlays of population density, slums, and vulnerable infrastructure (such as metro stations, hospitals, and roads) indicated high disproportionate exposure in high-density and low-income areas like Tondiarpet, Saidapet, and Perambur. The exercise also assisted in mapping service deserts, where there is no emergency response infrastructure such as shelters or health centers despite being located in flood-prone wards.

4.3.2. TEMPORAL ANALYSIS

The temporal aspect was investigated using comparative examination of satellite-determined land use and flood-related observations between the periods 1990, 2000, 2010, and 2023. The results indicate continuous growth of urbanized areas, especially in southern and western peripheries of Chennai, usually at the expense of green cover and waterbodies. For example, Pallikaranai Marshland has reduced by more than 60% between the periods 1991-2021 through encroachments and spontaneous real estate development. Rainfall pattern analysis, based on IMD and disaster records, also reflects a temporal trend of augmented rainfall intensity during Northeast Monsoon and an increase in high-intensity short-duration rainfall events, particularly after 2015. Mapping of the impact of floods of 2005, 2015, and 2023 overlaid revealed recurrence of inundation in particular zones despite post-flood infrastructure investments—indicating either insufficient coverage or failure of a system level in mitigation efforts.Additionally, socio-economic changes over the past two decades, such as increased informal settlement growth, urban sprawl into peri-urban floodplains, and demographic shifts in vulnerable zones, were temporally mapped to reflect changing patterns of exposure and sensitivity. These findings emphasize the need for dynamic flood risk models that are not only spatially targeted but also responsive to long-term urban transformations.The spatial and temporal analysis facilitated the identification of high-risk areas persistently high in risk, newly appearing hotspots, and systemic neglect zones, which are important for ranking mitigation interventions. This stratified approach ensures that flood risk assessment is not just considering static hazard conditions but also the dynamic nature of urban development, infrastructure planning, and environmental degradation in Chennai.

4.4. IDENTIFICATION OF KEY PARAMETERS

Urban flood risk is influenced by a complicated interaction between natural, constructed, and socio-economic systems. To design effective mitigation as well as adaptation strategies, it is vital to comprehend the general parameters that regulate flood behavior. These parameters are generally categorized into three broad categories—physical (hydrological and topographical), environmental, and human-induced (infrastructural and socio-economic) factors. On the physical side, rainfall intensity, duration, and frequency are the major drivers of flood events. But their influence is greatly modified by the topographic elements of slope, elevation, and terrain depressions that control surface runoff, water accumulation, and flow directions. In low-lying and plain city areas like Chennai, even moderate rainfall can lead to large waterlogging because of poor natural drainage gradients. From the environmental point of view, land cover and land use (LULC) are very important. The conversion of green areas, intrusions into water bodies and wetlands, and the growth of impervious surfaces enhance surface runoff while decreasing infiltration and retention. Cover and condition of drainage infrastructure such as storm drains, canals, and natural water courses are important parameters that determine directly the city's ability to drain excess water during and after precipitation. On the socio-economic and human aspect, factors like typology of housing, population density, and the existence of informal settlements dictate the extent to which a flood occurrence affects communities. Essential infrastructure, such as hospitals, transportation hubs, and schools within flood-risk areas, contributes to systemic risk. In addition, waste mismanagement, particularly in the context of solid waste clogging drainage inlets, also contributes to flash flooding within the urban setting, especially in high-density commercial and residential areas. Together, these factors provide an integrated framework to evaluate, forecast, and control flood risk. Quantifying them spatially and temporally allows planners and disaster management agencies to determine high-risk areas and design focused interventions that increase urban flood resilience.

4.5. RESEARCH GAP IDENTIFICATION

To ensure that the flood risk model developed in this study addresses critical limitations in existing research, a review of recent academic studies focused on Chennai’s flood risk was conducted. The selected studies span a range of methodologies including machine learning, comparative event analysis, PCA-based vulnerability assessment, and multi-criteria GIS mapping. While these works offer valuable contributions, a closer analysis reveals recurring methodological and data-related gaps that restrict their utility for holistic flood risk management.The literature reviewed, such as A. Kumar et al. (2023), S. Ramesh et al. (2023), P.S. Kumar et al. (2023), R. Sharma et al. (2023), and M. Natarajan et al. (2023), pointed out some key gaps. In particular:

- Single-year flood event studies cannot capture the temporal dynamics of flood risk with rapid urban change.
- Models tend to omit socio-economic aspects like slum density, informal settlements, and livelihood vulnerability that are important for equitable risk estimation.
- Integrated frameworks including hazard, exposure, and vulnerability (H-E-V) components are sparse and mostly considered in isolation, constraining systemic understanding.
- Land use and infrastructure dynamics, especially the influence of wetland loss, drainage capacity, and road networks, are typically omitted.
- Most studies prove weak model verification through historical flood events or empirical observations.

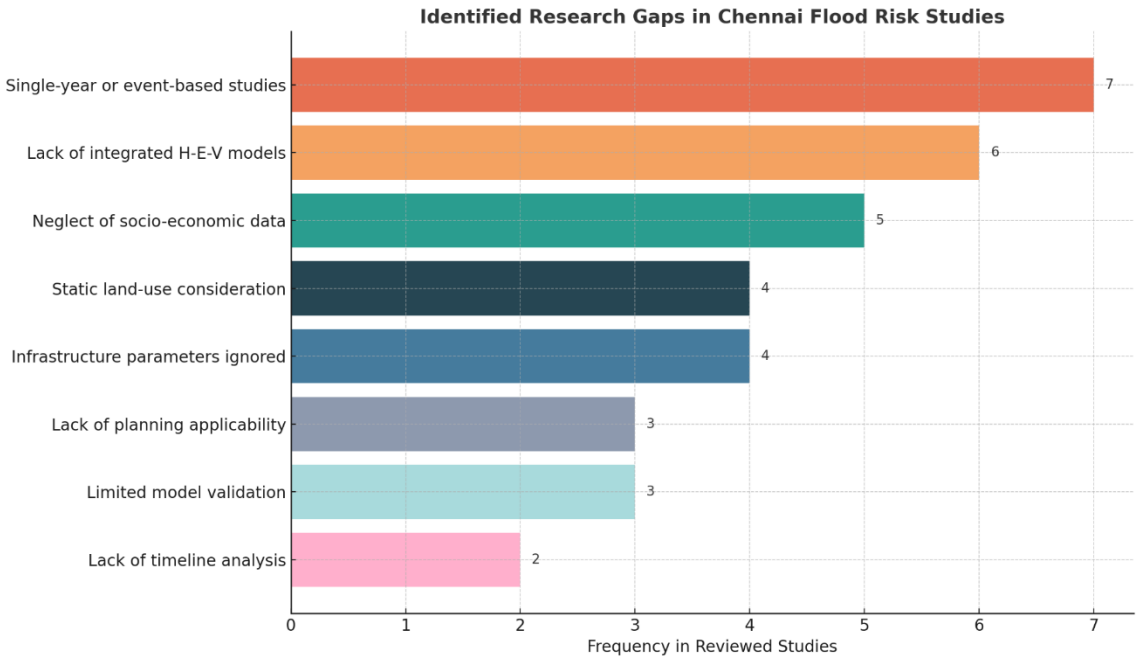

Figure 13 Research Gaps

The supporting evidence bar graph illustrates the repetitive pattern of such constraints within literature under review, highlighting calls to integrate dynamic city-wide processes with high-quality datasets and multi-faceted indicators of vulnerability.While research offers base-level methods to apply and case-specific findings, it mostly fails to confront the intricate, complex character of flood risk within an increasingly developing urban environment such as Chennai. Most studies adopt either a technical or social lens in isolation, lacking the cross-sectoral synthesis required for actionable flood management. This study attempts to bridge these gaps by integrating spatial, temporal, environmental, and socio-economic parameters into a unified, scalable flood risk model tailored to Chennai's urban realities.

CHAPTER 5 – FLOOD RISK MODEL

5.1. INTRODUCTION

To ensure that the flood risk model developed in this study addresses critical limitations in existing research, a review of recent academic studies focused on Chennai's flood risk was conducted. The selected studies span a range of methodologies including machine learning, comparative event analysis, PCA-based vulnerability assessment, and multi-criteria GIS mapping. While these works offer valuable contributions, a closer analysis reveals recurring methodological and data-related gaps that restrict their utility for holistic flood risk management.The literature reviewed, such as those by A. Kumar et al. (2023), S. Ramesh et al. (2023), P.S. Kumar et al. (2023), R. Sharma et al. (2023), and M. Natarajan et al. (2023), pointed out a number of shortcomings that are critical. Most significantly:

- Single-year flood event studies cannot capture the temporal development of flood risk against the backdrop of fast-paced urban change.
- Models tend to leave out socio-economic factors like slum density, informal housing, and livelihood vulnerability, essential for fair risk assessment.
- There is a significant lack of comprehensive frameworks that take H-E-V components into account simultaneously, restricting systemic understanding.
- Land use and infrastructure dynamics—especially the effect of wetland loss, drainage capacity, and road networks—are commonly neglected.
- Most studies illustrate poor model validation based on historic flood events or empirical observations.

The bar graph below illustrates the cyclical pattern of these limitations in literature reviewed, reflecting the necessity for models that integrate dynamic urbanity, sound datasets, and multi-dimensional indicators of vulnerability.It is a compound urban problem motivated by hydrometeorological occurrences, urban expansion, infrastructural strain, and socio-economic disparities. In measuring this risk systematically and contextually, the research in this paper employs a parameter-based Flood Risk Assessment Model, based on the widely used formula:

Flood Risk = Hazard × Exposure × Vulnerability

This format ensures that risk is not viewed as a solely physical phenomenon but as a product of dynamic interplay among environmental danger, societal state, and infrastructural capability.

5.2. PARAMETERS

5.2.1. PARAMETER SELECTION CRITERIA

The selection of parameters for flood risk assessment in this study followed a structured, multi-layered approach, combining international frameworks, local floods analysis, and practical considerations of data availability. Recognizing the phenomena of urban flooding not only by natural hazards but also by infrastructural gaps and socio-economic exposure related parameters were chosen to reflect Chennai's urban vulnerabilities and flood dynamics. The first step consisted of an extensive global literature and policy framework review, specifically the IPCC Climate Risk Framework (H × V × E), conceptualizing the flood risk as the conjunction of Hazard, Vulnerability, and Exposure. This framework gave the structure of the assessment. Apart from this, national protocols like NDMA Urban Flood Risk Protocols and international standards such as the UNDRR Urban Risk Index have been referred to ensure the study follows best global practices. Peer-reviewed scholarly research on flood modeling from other cities that are prone to floods—namely Mumbai, Dhaka, and Kolkata—also helped determine the frequently applied parameters such as rainfall intensity, green cover, land use change, drainage length, and population density. To make the choice local scenario based, an analysis specific to Chennai was conducted with a focus on the city's most significant flood instances, like in the years 2005, 2015, 2017, and 2021. The instances bring causes of floods like inadequate drainage in central areas, riverbank encroachments, high-density slum clusters, solid waste clogging of stormwater inlets, and poor early warning systems. These experienced deficiencies confirmed the applicability of certain indicators and directed their integration into the flood risk model.The second important layer of parameter screening entailed the testing of the quality and availability of the data. Parameters for which spatial data could be accessed or derived reliably were considered. Satellite-derived indices (e.g., NDVI, LULC, DEM), census data, Smart City maps, CMDA plans, IMD rainfall, and infrastructure records of GCC and TNSDMA were included. Parameters with outdated or non-geo-referenced datasets were dropped to ensure spatial modeling consistency. These parameters were then grouped under one of the three most important components: Hazard (40%), Vulnerability (30%), and Exposure (30%). The climatic and physical parameters under Hazard were annual rainfall, surface permeability, drainage coverage, and elevation. The parameters under Vulnerability represented the sensitivity and coping ability of populations and systems, such as informal settlements, loss of green cover, drainage blockages by solid waste, and the existence or non-existence of early warning systems. Exposure indicators overlaid the density and spatial coverage of individuals, economic resources, and essential infrastructure within flood-risk areas.Lastly, rigorous selection criteria

were enforced such that the chosen parameters are relevant, measurable, non-duplicate, obtainable, and validated from both real-world flood effects as well as data overlays. This is to ensure not just that the flood risk model is data based but also context sensitive and scalable. The result is a well-balanced, well structured, and holistic parameter framework that represents both international best practices as well as Chennai's individual urban flooding profile.

5.2.2. HAZARD PARAMETERS

The Hazard aspect takes care of the intensity, frequency, and environmental drivers of floods. Parameters chosen under this category denote the physical and climatological attributes causing or augmenting urban flooding in Chennai.

- **Annual Rainfall Intensity & Frequency:** Denotes the cyclical pattern of intense precipitation (e.g., cloudbursts, monsoon surges) resulting in surface runoff.
- **Surface Permeability / Impermeable Surface %:** Increased built-up area lowers infiltration, leading to quicker rainwater buildup.
- **Stormwater Inlet Coverage:** Describes the distribution and density of effective stormwater drainage inlets in urban areas.
- **Drainage Length / Coverage:** Records the overall extent and connectivity of stormwater drainage networks in individual administrative areas.

These measures are spatially examined to determine natural hazard-prone areas and places with physical inadequacies in evacuation of floodwaters.

5.2.3. VULNERABILITY PARAMETERS

Vulnerability is a measure of the sensitivity of systems and communities to the effects of floods and their ability to recover and adapt. This element incorporates environmental degradation and institutional capacity deficiencies.

- **Decline of Green Cover:** Loss of urban vegetation and pervious surfaces reduces the natural capacity of the city to retain rainwater.
- **Incidence of Informal Settlements:** Suffering in slums and poorly built dwellings takes a greater toll in damage, displacement, and recovery.
- **Solid Waste Blockage Index:** Tracks frequency and intensity of drain clogs caused by uncollected waste—prevalent in poor and densely populated wards.
- **Early Warning System (EWS) Availability:** Regions with delayed flood warnings and community-level early warning systems are more vulnerable.

By measuring these layers, the model identifies weaknesses in the system and population clusters disproportionately at risk to flood-related hazards.

5.2.4. EXPOSURE PARAMETERS

The Exposure element assesses the amount of population and infrastructure of importance that are exposed to risk because they happen to be in flood-prone areas. This indicates the size and magnitude of elements that could be affected in case of flooding.

- **Population Density**: Higher population per square kilometer increases human impact whenever flooding happens.
- **Slum Population Proportion:** Determines marginal populations with low resilience and high vulnerability to water stagnation.
- **Vulnerable Infrastructure**: Overlays key urban facilities—like hospitals, metros, transport routes—within areas of flood danger.
- **Economic Assets:** Comprises industries, markets, service nodes whose flooding can result in out-of-proportion economic loss and disruption.

This category ensures that high-density and high-value urban areas are marked for advance mitigation and disaster planning.

5.2.5. Model Relevance and Adaptability

This model is strongly consistent with IPCC AR6 and UNDRR frameworks but based on local conditions utilizing Chennai-relevant data sources (GCC, CMDA, IMD, Census, satellite imagery).

It fulfills primary research gap identified in previous research by:

- Synthesizing H-E-V components in a single framework
- Including socio-economic and environmental stressors
- Including spatial and temporal flood risk layers
- Facilitating ward-wise and zone-wise comparative risk classification

The adopted flood risk model is both a diagnostic tool and a decision-support system. It allows planners, researchers, and disaster management agencies to pinpoint key risk areas, rank interventions, and develop long-term resilience in the face of escalating flood threats in the Chennai Metropolitan Area. While current research offers fundamental methods and case-specific analysis, it is largely short in conceptualizing the

multi-scalar, complex nature of flood risk within a rapidly transforming metropolitan setting such as Chennai. Most studies apply either a technical or social perspective in isolation, without cross-sectoral synthesis aimed at flood management actionability. This study attempts to bridge these gaps by integrating spatial, temporal, environmental, and socio-economic parameters into a unified, scalable flood risk model tailored to Chennai's urban realities.

5.3. STRUCTURE OF FLOOD RISK MODEL

To quantify the flood risk model, every chosen parameter was given a quantitative value range, risk category, and score, by relying on official standards and context-based benchmarks. The scoring system enables uniform comparison across spatial units and ensures objectivity in identifying flood-prone areas.All the parameters were classified under four categories: Very High Risk, High Risk, Moderate Risk, and Low Risk, and labelled with respective scores of 1.0, 0.7, 0.4, and 0.1 respectively. The thresholds for scoring were taken from trusted government documents, international standards, and scientific literature to ensure reliability and applicability in the Chennai city.

Parameters within the Hazard category are the physical causes of the flooding like volume of rain, density of stormwater infrastructure, and permeability of the ground. Annual Rainfall (mm): Locations that received >1600 mm were classified as "Very High Risk", whereas areas that received <1000 mm were labeled with a "Low Risk" value.Drain to Road Ratio: A ratio <0.5 indicates inadequate drainage, scoring 1.0 (Very High Risk). Values >1.0 imply sufficient coverage. These thresholds were derived from CMDA planning standards. Inlets per hectare: Inlet density <1/ha indicates drainage under-provisioning, while >3 inlets/ha suggests more coverage. Benchmarks were taken from MoHUA infrastructure guidelines. Surface Permeability (%): High developed areas with <20% permeable surfaces are regarded as high flood risk owing to concentration of runoff. Source: BIS codes and Urban Flood Index references. The Vulnerability parameters describe the ability of communities and systems to respond to flood events. These parameters express social inequality, condition of infrastructure, and environmental degradation. Green Cover (%): <20% vegetation cover was considered Very High Risk. NDVI-based thresholds conform to NASA/ISRO guidelines. Informal Settlements (%): >50% signifies a large proportion of risk-prone populations, according to UN-Habitat risk frameworks. Solid Waste Blockage (%): Drain blockage >50% is strongly correlated with flooding, as per Swachh Bharat Urban parameters. Early Warning System (EWS) (%): Low flood alert covering (<30%) high vulnerability, as per NDMA alert distribution guidelines.Exposure parameters establish the extent of population and infrastructure located in flood-prone areas. Population Density (ppl/sq.km): Wards with >35,000 people/km² were assigned a Very High Risk rating, against UNDRR urban density thresholds.Slum Population (%): Localities with over 60% of slum population indicate high vulnerability to poor infrastructure and slow

recovery, according to World Bank urban poverty indicators. Vulnerable Infrastructure (%): Proportion of hospitals, schools, and transport buildings in flood-prone areas was rated on the basis of CMDA's infrastructure risk prioritization matrix. Economic Assets in Risk Zones (%): Regions with >60% commercial zones in flood risk areas were assessed as Very High Risk, with thresholds mapped according to the IPCC Urban Risk Framework. Each unit of analysis or ward is given parameter-specific scores depending on its data category. They are then multiplied by their corresponding component weights (Hazard – 40%, Vulnerability – 30%, Exposure – 30%) to calculate a composite Flood Risk Index (FRI). The total score allows for ranking areas into flood risk classes: Low, Moderate, High, and Very High, which are also mapped spatially in GIS maps

Category	Parameter	Range (Very High → Low)	Score (VH → L)	Source
Hazard	Annual Rainfall (mm)	>1600 / 1400–1600 / 1000–1400 / <1000	1 / 0.7 / 0.4 / 0.1	IMD, CWC Regional Studies
Hazard	Drain to Road Ratio	<0.5 / 0.5–0.75 / 0.75–1.0 / >1.0	1 / 0.7 / 0.4 / 0.1	CMDA Benchmarks
Hazard	Inlets per hectare	<1 / 1–2 / 2–3 / >3	1 / 0.7 / 0.4 / 0.1	MoHUA Manuals
Hazard	Surface Permeability (%)	<20 / 20–30 / 30–50 / >50	1 / 0.7 / 0.4 / 0.1	BIS, Urban Flood Index
Vulnerability	Green Cover (%)	<20 / 20–30 / 30–50 / >50	1 / 0.7 / 0.4 / 0.1	NDVI (NASA/ISRO)
Vulnerability	Informal Settlements (%)	>50 / 30–50 / 10–30 / <10	1 / 0.7 / 0.4 / 0.1	UN-Habitat Slum Definitions
Vulnerability	Solid Waste Blockage (%)	>50 / 30–50 / 10–30 / <10	1 / 0.7 / 0.4 / 0.1	Swachh Bharat Urban Waste Indicators
Vulnerability	EWS Access (%)	<30 / 30–50 / 50–80 / >80	1 / 0.7 / 0.4 / 0.1	NDMA EWS Guidelines
Exposure	Population Density (ppl/sq.km)	>35K / 25–35K / 10–25K / <10K	1 / 0.7 / 0.4 / 0.1	UNDRR Urban Density Guidelines
Exposure	Slum Population (%)	>60 / 40–60 / 20–40 / <20	1 / 0.7 / 0.4 / 0.1	World Bank Urban Poverty Metrics
Exposure	Vulnerable Infrastructure (%)	>50 / 30–50 / 15–30 / <15	1 / 0.7 / 0.4 / 0.1	CMDA Risk-Based Asset Prioritization
Exposure	Economic Assets in Risk Zones (%)	>60 / 40–60 / 20–40 / <20	1 / 0.7 / 0.4 / 0.1	IPCC Urban Risk Framework

Table 5 Structure of Flood risk Model

5.3.1. FLOOD RISK MODEL

FLOOD RISK MODEL - HAZARD 40% + VULNERABILITY 30% + EXPOSURE 30% = RISK (100)

PARAMETER	SUB- PARAMETER	UNIT	WEIGHTAGE	SCORING RANGE	OVERALL WEIGHTAGE
HAZARD PARAMETERS	ANNUAL RAINFALL	mm	0.25	0.1 (≤1000) – 1 (≥1600)	HAZARD PARAMETER SCORE -01 OVERALL WEIGHTAGE - 40 PERCENTAGE SCORE - 01 X 04 = 04
	SURFACE PERMEABILITY	%	0.25	0.1(>60) - 1 (<20)	
	DRAIN TO ROAD LENGTH RATIO	km	0.25	0.1 (≥1) – 1 (≤0.5)	
	STROMWATER INLET COVERAGE	inlets/ha	0.25	0.1 (<3) – 1 (>1)	
VULNERABILITY PARAMETERS	GREEN COVER / VEGETATION	%	0.25	0.1(>50) - 1 (<20)	VULNERABILITY PARAMETER SCORE -01 OVERALL WEIGHTAGE - 30 PERCENTAGE SCORE - 01 X 03 = 03
	INFORMAL SETTLEMENTS	%	0.25	0.1(<10) - 1 (>30)	
	SOLID WASTE BLOCKAGE INDEX	%	0.25	0.1(<10) - 1 (>30)	
	EARLY WARNING SYSTEM (EWS)	%	0.25	0.1(>80) - 1 (<50)	
EXPOSURE PARAMETERS	POPULATION DENSITY	ppl/sq.m	0.25	0.1(<10k/sq.m) - 1 (>25k/sq.m)	EXPOSURE PARAMETER SCORE - 01 OVERALL WEIGHTAGE - 30 PERCENTAGE SCORE - 01 X 03 = 03
	SLUM POPULATION	%	0.25	0.1(<20) - 1 (>40)	
	VULNERABLE INFRASTRUCTURE	%	0.25	0.1(<15) - 1 (>30)	
	ECONOMIC ASSETS	%	0.25	0.1(<20) - 1 (>40)	
RISK SCORE					**04+03+03 = 10**

Table 6 Flood Risk Model - Chennai City

CHAPTER 6 – FINDINGS & DISCUSSION THROUGH MODEL

6.1. CURRENT RISK SCENARIO OF CHENNAI (2024)

PARAMETER	SUB- PARAMETER	UNIT	2024	LEVEL OF RISK	SCORE
HAZARD PARAMETERS	ANNUAL RAINFALL	mm	1550	0.6(High Risk)	0.7
	SURFACE PERMEABILITY	%	22	0.7 (High Risk)	0.7
	DRAINAGE LENGTH	km/km	0.56	0.7 (High Risk)	0.7
	STROMWATER INLET COVERAGE	inlets/ha	2.5	0.4 (Moderate Risk)	0.4
HAZARD SCORE -					2.5
VULNERABILITY PARAMETERS	GREEN COVER / VEGETATION	%	12	1 (Very High Risk)	1
	INFORMAL SETTLEMENTS	%	24	0.4 (Moderate Risk)	0.4
	SOLID WASTE BLOCKAGE INDEX	%	22	0.4 (Moderate Risk)	0.4
	EARLY WARNING SYSTEM (EWS)	%	80	0.4 (Moderate Risk)	0.4
VULNERABILITY SCORE -					1.65
EXPOSURE PARAMETERS	POPULATION DENSITY	ppl/sq.m	20000	0.4 (Moderate Risk)	0.4
	SLUM POPULATION	%	24	0.4 (Moderate Risk)	0.4
	VULNERABLE INFRASTRUCTURE	%	14	0.1 (Low Risk)	0.1
	ECONOMIC ASSETS	%	55	0.7 (High Risk)	0.7
HAZARD SCORE -					1.2

RISK FACTOR	
HAZARD	2.5
VULNERABILITY	1.65
EXPOSURE	1.2
TOTAL	5.350

Table 7 Flood Risk Assessment - 2024

Parameters were grouped into three main components: **Hazard, Vulnerability, and Exposure**, according to the IPCC Risk Framework.Hazard parameters are the physical and climatic signs of flood. There were four sub-parameters examined:

- Annual Rainfall (1550 mm) – High-risk category (score: 0.7)
- Surface Permeability (22%) – Indicates a strongly impervious surface that results in increased runoff (score: 0.7)
- Drainage Length (0.56 km/km) – Low-to-moderate network density that increases flood occurrence (score: 0.7)
- Stormwater Inlet Coverage (2.5 inlets/ha) – Moderate risk category as per MoHUA standards (score: 0.4)

The overall Hazard Score from these factors is 2.5, a relatively high hazard profile in the study area. Vulnerability is able to capture the exposure of the population and urban networks to the impact of floods. The most critical four indicators are:

- Green Cover (12%) – Very low plant cover, increasing flood retention time (score: 1.0)
- Informal Settlements (24%) – Low density of unorganized housing (score: 0.4)
- Solid Waste Blockage Index (22%) – Moderate risk of clogged drains due to unattended waste (score: 0.4)
- Early Warning System Access (80%) – Good access, which reflects lower vulnerability (score: 0.4)
- Total Vulnerability Score is 1.65, where green cover is the highest driver of vulnerability in this instance. Exposure quantifies the population and economic assets within areas that are at risk of flood and can augment the scale of disaster losses. The following were considered:
- Population Density (20,000 ppl/sq.km) – Moderate exposure score (0.4)
- Slum Population (24%) – Moderate-level informal settlement density (score: 0.4)
- Vulnerable Infrastructure (14%) – Low risk due to limited critical infrastructure in hazard zones (score: 0.1)
- Economic Assets in Risk Zones (55%) – High exposure of businesses and industry (score: 0.7)

The total Exposure Score is 1.2, indicating localized economic exposure against a backdrop of moderate population risk.

The component scores were all summed up to determine the overall flood risk index for 2024:

- Hazard - 2.50/4
- Vulnerability - 1.65/3
- Exposure - 1.20/3

Total Risk - 5.35 /10

This is a composite risk score of 5.35 that indicates a high to moderate overall flood risk requiring multi-dimensional mitigation interventions—specifically the improvement of green infrastructure and drainage systems.

6.2. FLOOD RISK ASSESSMENT – 2011-2024

PARAMETER	SUB- PARAMETER	UNIT	2011	SCORE	2015	SCORE	2020	SCORE	2024	SCORE
HAZARD PARAMETERS	ANNUAL RAINFALL	mm	1,400	0.7	1,600	1	1,500	0.7	1,550	0.7
	SURFACE PERMEABILITY	%	35	0.7	30	0.7	25	0.7	22	0.7
	DRAINAGE RATIO	km	0.43	1	0.50	0.7	0.55	0.7	0.56	0.7
	STROMWATER INLET COVERAGE	inlets/ha	1.5	0.7	1.8	0.7	2.2	0.4	2.5	0.4
VULNERABILITY PARAMETERS	GREEN COVER / VEGETATION	%	18	1	16	1	14	1	12	1
	INFORMAL SETTLEMENTS	%	30	0.4	28	0.4	26	0.4	24	0.4
	SOLID WASTE BLOCKAGE INDEX	%	15	0.4	18	0.4	20	0.4	22	0.4
	EARLY WARNING SYSTEM (EWS)	%	10	1	30	0.7	60	0.4	80	0.4
EXPOSURE PARAMETERS	POPULATION DENSITY	ppl/sq.m	15,840	0.4	17,000	0.4	18,500	0.4	20,000	0.4
	SLUM POPULATION	%	30	0.4	28	0.4	26	0.4	24	0.4
	VULNERABLE INFRASTRUCTURE	%	25	0.4	23	0.4	20	0.4	14	0.1
	ECONOMIC ASSETS	%	40	0.4	45	0.7	50	0.7	55	0.7
		HAZARD (40)		3.1		3.1		2.5		2.5
		VULNERABILITY (30)		2.1		1.875		1.65		1.65
		EXPOSURE (30)		1.2		1.425		1.425		1.2
		RISK		6.4		6.4		5.575		5.35

Table 8 Flood Risk Assessment - A Decade

Flood risk analysis of Chennai for a decade shows significant changes in the intensity of the hazard, patterns of vulnerability, and zones of exposure. After analyzing all 12 parameters classified under Hazard (40%), Vulnerability (30%), and Exposure (30%), this research gives an integrated overview of the changes in flood risk from 2011 to 2024. Scoring is based on standardized ranges that allow assigning risk values to facilitate consistent comparison over time. **Hazard parameters** correspond to the physical immediate triggers of floodings, such as rainfall intensity, permeability, drainage, and coverage of inlets. During this duration, the hazard score **decreased from 3.1 in 2011 and 2015 to 2.5 in 2020 and 2024, with minimal improvement.** Annual rainfall remained consistently high, peaking at 1600 mm in 2015 (score: 1.0), compared with

Chennai's historic floods. Although there was a marginal decline post-2015, rainfall still remained above 1500 mm, posing continued hydrological pressure. Surface permeability reduced significantly from 35% in 2011 to just 22% in 2024, reflecting a steady increase in built-up and paved surfaces, which limits natural infiltration and increases runoff. Drainage ratios increased slightly, indicating modest but increasing investment in stormwater facilities. Similarly, coverage of stormwater inlets almost doubled from 1.5 inlets/ha in 2011 to 2.5 inlets/ha in 2024, minimizing flood stagnation time in specific spots. Though infrastructural improvement has been made, urban compaction and trends in rainfall keep the levels of hazard moderately elevated. **Vulnerability indicators** measure the ability of communities and the environment to resist flood effects. Over 2011-2024, vulnerability was down **from 2.1 to 1.65, a relative improvement—still with ongoing ecological stress.** Greenery cover was still at critical levels at 12%, maintaining a risk score constant at 1.0 (Very High). This indicates prevailing ecological deterioration, without any meaningful restoration despite realization. Informal settlements declined gradually from 30% to 24%, indicating step-by-step work in resettlement or the upgrade of housing. Solid waste clogging deteriorated, increasing from 15% in 2011 to 22% in 2024. This indicates poor municipal solid waste management, especially around drainage systems. One success story is the enhancement of early warning system (EWS) access, which rose from mere 30% in 2011 to 80% in 2024—enhancing disaster communication and response systems. Total, vulnerability decreased as a result of institutional improvements, although environmental factors remain the same or aggravating.

Exposure refers to the extent of population and infrastructure exposed to floods. **The exposure score was fluctuating around 1.2–1.425, with minimal change over time.** The population density has seen a sharp increase, from 15,840 persons/sq.km in 2011 to 20,000 in 2024. Such a quick densification of urban areas exacerbates urban exposure to flood hazard, particularly for poorly drained wards. Slum population decreased moderately, an indicator of continued efforts toward bettering the housing situation, but still many are found in canal-side or low-lying areas. Vulnerable infrastructure (transport, utility, hospitals) in flood zones decreased significantly from 25% to 14%, as a result of targeted retrofit and planning.Yet, economic exposures to floods rose consistently, from 45% to 55%, moving the flood risk of the city towards commercial and industrial sectors. This reveals an additional dimension of financial vulnerability, particularly in such hubs as Taramani, Ambattur, and Guindy. Therefore, even though resilience in infrastructure had risen, economic exposure has emerged as the new flood risk hotbed.

6.3. CRITICAL PARAMETERS

Category	Parameter	Trend	Explanation
Vulnerability	Green Cover	Decreased (18% to 12%)	Loss of green spaces increases flood vulnerability due to reduced infiltration.
Hazard	Annual Rainfall	Slightly increased	Monsoonal variability with high-intensity rainfall increases hazard.
Hazard	Surface Permeability	Decreased (35% to 22%)	Urban surfaces becoming impermeable, leading to higher runoff.
Hazard	Drainage Ratio	Improved slightly (0.43 to 0.56)	Drainage network improving but still insufficient for flood demand.
Exposure	Economic Assets	Increased (40% to 55%)	Growing commercial activity in risk-prone zones increases exposure.
Exposure	Population Density	Increased (15,840 to 20,000)	More people in dense zones increases potential impact of flooding.
Hazard	Stormwater Inlet Coverage	Improved (1.5 to 2.5 inlets/ha)	Stormwater infrastructure improved, helping reduce waterlogging.
Vulnerability	Informal Settlements	Decreased (30% to 24%)	Resettlement efforts reduce vulnerability slightly in slum areas.
Vulnerability	Solid Waste Blockage Index	Increased (15% to 22%)	More waste clogging drains, worsening urban flood risk.
Vulnerability	Early Warning System	Improved (10% to 80%)	Better warnings and alert systems have reduced vulnerability.
Exposure	Slum Population	Decreased (30% to 24%)	Resettlements reduce exposure marginally, but risks persist.

Exposure	**Vulnerable Infrastruc-ture**	**Improved (25% to 14%)**	**Upgraded hospitals and critical infrastructure improve resilience.**

Table 9 Critical Parameters

Flood risk analysis between 2011 and 2024 shows a combination of advancements and emerging issues. And the most alarming trend is reduced green cover, which fell from 18% to 12%. This uniform loss of vegetated covers throughout the city has tremendously compromised infiltration capacity, consequently raising the surface runoff as well as flood exposure. In the same way, **surface permeability decreased from 35% to 22%,** further proof that Chennai's urban growth is highly dependent on impervious surfaces like concrete and asphalt. Nevertheless, progress was made in stormwater infrastructure—**the drainage ratio increased modestly from 0.43 to 0.56**, and stormwater inlet coverage improved from 1.5 to 2.5 inlets per hectare. These improvements reflect incremental investments in physical facilities, though still short of entirely reducing flood hazards. On the hazard side, rainfall annually has risen slightly, with increased variability and more frequent periods of extreme rainfall, likely associated with wider climate change tendencies. This adds to an increased hazard score, in spite of infrastructure improvements. In relation to exposure, **population density also increased significantly, from 15,840 to 20,000** persons per sq.km, so more individuals are now dwelling in high-risk flood areas. Besides, **economic assets in flood areas have risen from 40% to 55%,** indicating commercial activity and key economic infrastructure are increasingly exposed. Vulnerability parameters paint a more intricate picture. **Informal settlements have declined moderately, from 30% to 24%**, through resettlement and housing programs, but most of them are still located in marginal conditions. Slum numbers have also decreased over the years, but the risk of exposure still exists due to siting and the absence of tenure security**. Blockage due to solid waste has increased, from 15% to 22%,** indicating municipal failures in solid waste management and its contribution to blockages in drains of the city. On the other side, early warning system coverage is much better now, from **10% to 80%,** an indication of improved communication capacity and institutional readiness.Overall, although Chennai has made real progress in certain respects—early warning systems, drainage grates, and elimination of slums—the city's flood risk remains significant. The combined challenge of **increasing urban density and shrinking ecological buffers** continues to cancel out the progress being made through policy and infrastructure, demonstrating the necessity of a more systemic, climate-sensitive urban planning strategy.

6.4. ISSUE IDENTIFICATION IN CHENNAI CITY

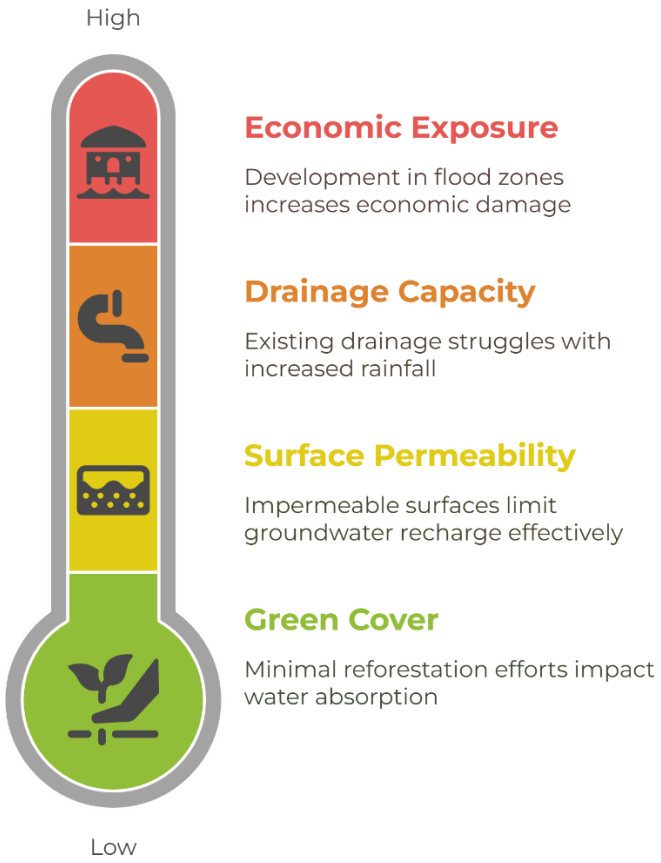

Figure 14 Issue Identification of Chennai City

Despite exceptional progress in infrastructure, several outstanding issues remain that increase the risk of flooding in Chennai, especially regarding factors like green cover, surface permeability, drainage capacity, and economic exposure. Firstly, the loss of green cover continues to be a matter of concern. Buildings and constructions have taken up open spaces, wetlands, and parks, and there is hardly any reforestation taking place. Upkeep of routine planting work is weak, and buffer zones around green water bodies are taken up or inadequately demarcated. Demand from institutions for the maintenance or restoration of green infrastructure is causing this loss. Second, the surface permeability decreases because impermeable surfaces are employed on roads, driveways, and pavements. Private developments under building controls do not require pervious surfaces, and the regulations of rainwater harvesting systems are not tight enough, hence restricting groundwater recharge. Intrusions by soft landscape and unregulated hardscaping in urbanized domestic and commercial areas also lower natural infiltration. As far as flood draining is concerned, the drainage ratio remains inadequate, particularly in the old and newly urbanized areas. The majority of areas still operate with previous networks designed for earlier rainfall levels. Drain dimension variability, lack of

adequate slope, and inadequate coverage lead to localized water buildup. Additionally, drains are also blocked by silt or solid waste due to the absence of regular desilting operations and a lack of public awareness. Lastly, rising concern can be seen about the higher exposure of economic assets to flood areas. Information technology parks, industrial parks, commercial belts, and logistics parks are being constructed on low-lying areas or on land reclamation without adequate assessment of flood effects. Zoning policies lack effective flood mitigation buffers, and Environmental Impact Assessments (EIAs) lack comprehensive hydrological modeling at the micro level, hence subjecting high-value economic assets to damage during extreme weather conditions.

6.5. DISCUSSION

Despite exceptional progress in infrastructure, several outstanding issues remain that increase the risk of flooding in Chennai, especially regarding factors like green cover, surface permeability, drainage capacity, and economic exposure.Firstly, the loss of green cover continues to be a matter of concern. Buildings and constructions have taken up open spaces, wetlands, and parks, and there is hardly any reforestation taking place. Upkeep of routine planting work is weak, and buffer zones around green water bodies are taken up or inadequately demarcated. Demand from institutions for maintenance or restoration of green infrastructure is causing this loss.Second, the surface permeability decreases because impermeable surfaces are employed on roads, driveways, and pavements. Private developments under building controls do not require pervious surfaces, and the regulations of rainwater harvesting systems are not tight enough, hence restricting groundwater recharge. Intrusions by soft landscape and unregulated hardscaping in urbanized domestic and commercial areas also lower natural infiltration. As far as flood draining is concerned, the drainage ratio remains inadequate, particularly in the old and newly urbanized areas. The majority of areas still operate with previous networks designed for earlier rainfall levels. Drain dimension variability, lack of adequate slope, and inadequate coverage lead to localized water buildup. Additionally, drains are also blocked by silt or solid waste due to the absence of regular desilting operations and lack of public awareness.Lastly, rising concern can be seen about the higher exposure of economic assets to flood areas. Information technology parks, industrial parks, commercial belts, and logistics parks are being constructed on low-lying areas or on land reclamation without adequate assessment of flood effects. Zoning policies lack effective flood mitigation buffers, and Environmental Impact Assessments (EIAs) lack comprehensive hydrological modeling at the micro level, hence subjecting high-value economic assets to damage during extreme weather conditions.

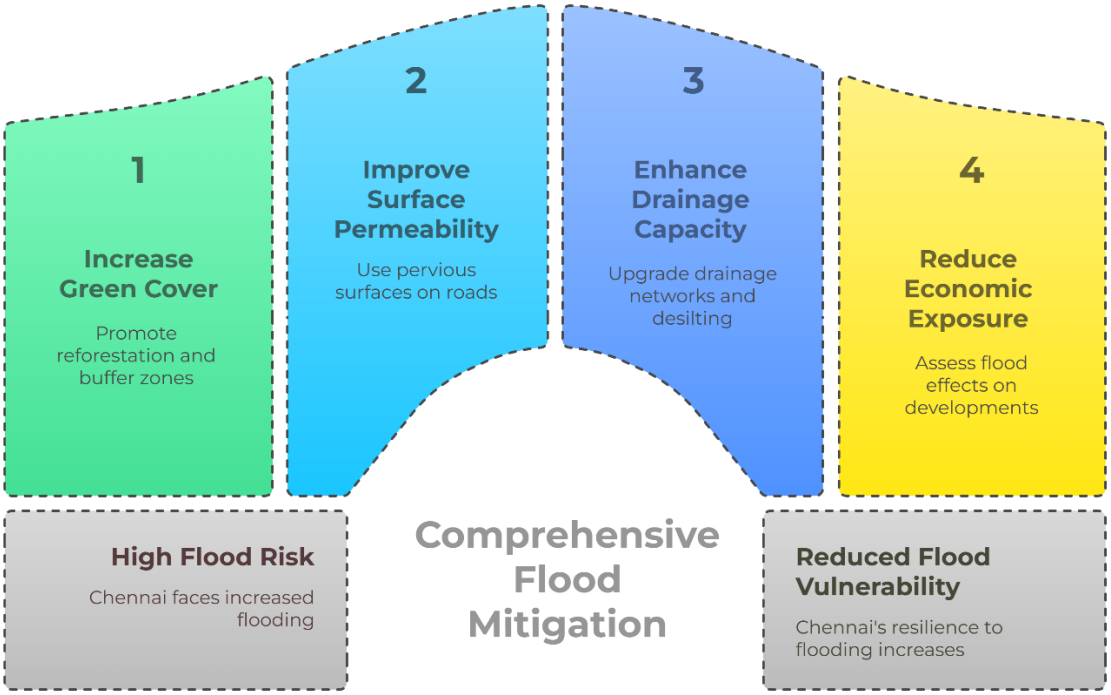

Figure 15 Results after the discussion

CHAPTER 7 – RECOMMENDATIONS

7.1. PROPOSALS

7.1.1. POLYCENTRIC GROWTH STRATEGY

To minimize economic exposure during flooding, one of the most long-term and sustainable options for Chennai is to encourage **“Decentralized Commercial Clusters”** through spatial planning. At present, the economic activities of the city are too concentrated in flood-prone locations like T. Nagar, Parry's Corner, George Town, Velachery, and the Koyambedu market area. These areas are highly prone to flooding risks due to their low-lying topography and weak drainage capacity. During heavy monsoon seasons, the interruption of businesses in these regions results in huge economic losses, affecting from retail and wholesale trade to the IT industry.The suggestion includes identifying and planning **"Alternative commercial nodes"** in safer, well-drained zones like **"Minjur, Tirumazhisai, Vandalur–Kelambakkam corridor, and Outer Ring Road junctions"**. These regions are on higher ground and provide space for expansion. By deconcentrating economic activities, the city can minimize the risk exposure as a whole and spread commercial activity more evenly. These new points can be planned under the direction of CMDA's **"Area Development Unit (ADU)"** or satellite town planning initiatives. Each location would be planned with combined stormwater management, raised access roads, climate-resilient design, and better logistics connectivity.In order to attract businesses to shift or set up shop in these areas, the government may provide **“financial incentives”** like FAR relaxation, lower property tax, and subsidized lease prices. **“Small traders, MSMEs, and wholesale operators”** must be given special importance and could be offered joint facilities and initial-stage infrastructure. Furthermore, involving trade bodies and urban cooperative banks to facilitate this move would help bring about improved stakeholder alignment.

This decentralization, besides increasing the “economic resilience of Chennai,” reduces pressure on central infrastructure, improves job distribution in the suburbs, and aligns with the “polycentric growth vision” for the future “3rd Master Plan (2027–2047)” of Chennai. By strategically redistributing commercial areas, the city can significantly limit flood-related economic disruption while promoting more balanced urban development.

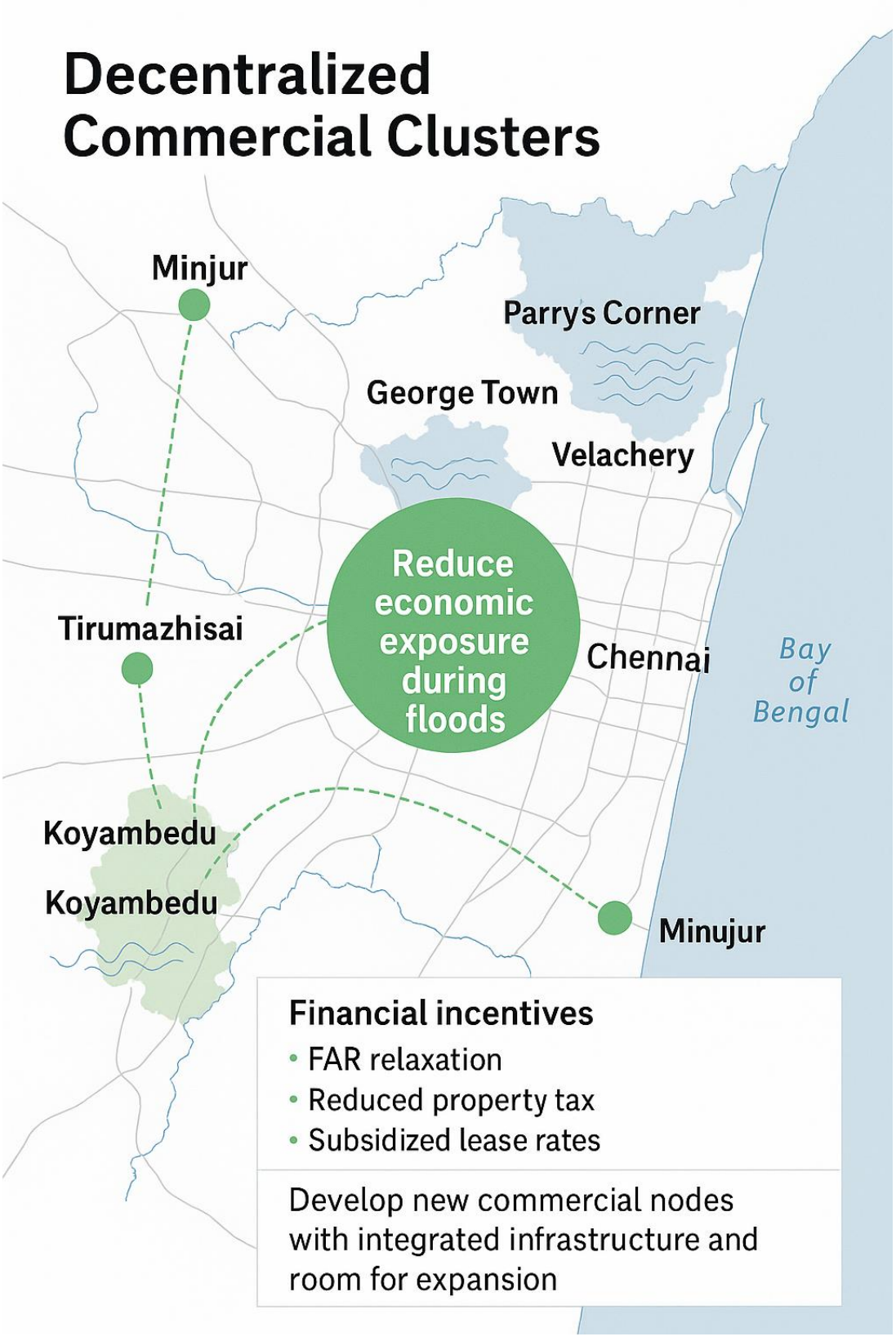

Figure 16 Polycentric Growth Vision

7.1.2. STORM WATER DRAIN – PHYSICAL BARRIERS

PREVENT SOLID WASTE AND SILT ENTRY INTO DRAINS
A major cause of urban flooding in Chennai is drain clogging by plastic waste, debris, and organic matter during monsoons – well-designed stormwater drains (SWDs) can overflow due to blocked inlets.
IMPLEMENTATION STRATEGY
GRIT AND TRASH TRAPS
Install silt chambers or bar screens before inlets at vulnerable locations (e.g. T. Nagar, Koyambedu)
SMART INLET DESIGNS
Redesign grates to capture less solids and allow easier cleaning access
ROUTINE DESILTING
Map inlets on GIS platform and assign regular maintenance schedules
ENFORCEMENT & AWARENESS
Impose fines for dumping near drains and run ward-level campaigns
EXPECTED IMPACT
30–40% reduction in waterlogging complaints during moderate rainfall
Longer operational lifespan of SWDs
Improved water quality and fewer disease outbreaks

Figure 17 Prevent SW in Drains

One of the most crucial and efficient steps to control urban flooding in Chennai is to **"stop solid waste and silt entry into the stormwater drainage system".** Blockage of drainage by **"plastic waste, construction material, leaves, and organic waste"** is one of the main causes of overflow during the monsoon season. Even if the design of stormwater drains (SWDs) is good and technically correct, their performance is impacted due to choked inlets and decreased internal flow capacity. This results in huge water stagnation, property loss, traffic gridlock, and an increased risk of vector-borne diseases. The issue is more severe in "**high-density and commercial zones like T. Nagar, Koyambedu Market, and Washermanpet",** where drain misuse and dumping of solid waste take place. To do so, the proposal recommends a multi-pronged approach: the installation of **"pre-fabricated silt chambers, grit traps, and trash barriers"** at intake points throughout the city. This physical equipment will be used to trap non-degradable refuse and silt before they reach the main drains. Open roadside drains can be equipped with **"vertical bar screens or mesh baskets",** which can be easily removed and cleaned after heavy rain. Apart from that, **"inlet grates"** need to be redesigned into "permitting improved water flow while stopping larger fragments of trash from entering the system. These grates need to be designed for "**ease of cleaning and maintenance"**, particularly on busy city streets. To make it more effective in the long run, a **"GIS-based drain inventory and maintenance tracking system"** needs to come into place. All inlets and drain segments need to **be "geo-tagged and given a cleaning schedule"**, with "mobile apps allowing engineers to log desilting work" through timestamped and photo'd evidence. This enhances transparency and accountability. Apart from that, strict **"enforcement of penalties"** under the **"Solid Waste Management Rules, 2016"** needs to be carried out to deter illegal dumping of waste along drains. To support enforcement, a robust community outreach component needs to be initiated—such as "ward-level awareness campaigns branded as **'Namma Drain – Namma Kaval" (Our Drain – Our Responsibility).** These campaigns can encourage residents, shopkeepers, and vendors to take local drainage health as their responsibility. Rolling out fully, this proposal is projected to "curb waterlogging grievances by 30–40% in moderate rains", prolong the life expectancy of Chennai's stormwater drainage system, and lead to "better water quality and fewer outbreaks of disease". By combining engineering interventions, digital monitoring, police enforcement, and behavioral changes, Chennai can hugely enhance its urban flood resilience.

7.1.3. SURFACE PERMEABILITY – BYE LAWS

7.1.3.1. PERMEABLE PAVEMENTS IN ZONAL REGULATIONS

Urbanization of Chennai has led to extensive application of impervious materials as pavement for driveways, car parks, and walkways, drastically reducing the natural recharge of groundwater. The practice has already directly caused augmented surface runoff, localized flooding, and loss of ecological balance, especially in high-density

commercial and residential zones. In a bid to do away with it, the proposal suggests a revision of the Development Control Regulations (DCR) under CMDA and GCC to require the application of permeable pavement materials on all new projects above specified thresholds. According to this regulation, residential plots larger than 100 sq.m, shopping complexes, institutional campuses, public spaces, and transport-related facilities such as bus bays and parking lots would be made to employ approved permeable materials such as porous concrete, interlocking pavers with sand joints, grass pavers (Grasscrete), and crushed gravel. These materials not only permit infiltration of water but also dissipate surface heat by evapotranspiration. The strategy for implementation involves incorporating clear guidelines in planning permissions, providing model construction details to developers, and training contractors to best practice.Pilot implementation for congested flood-vulnerable areas like T. Nagar, Marina Loop Road, and Velachery MRTS can be utilized for showing effectiveness and generating public and political acceptance. This intervention will increase infiltration of stormwater, reduce urban heat islands, and reduce the frequency of flash floods, thus being in line with Chennai's climate resilience and water conservation objectives.

7.1.3.2. MINIMUM OPEN SOIL AREA STANDARDS

In most localities of Chennai, especially in private plotted schemes, the plots are usually completely paved or constructed on, with barely any unpaved ground area for water percolation. This excessive concretization has seriously compromised groundwater recharge potential and increased run-off from the surface during rains. In order to counter this, the provision of a minimum Open Soil Ratio (OSR) should be made compulsory for all new development in the residential, commercial, and institutional areas. The proposed norms are to have at least 25% open-to-sky ground surface area on residential plots measuring more than 150 sq m, and 15–20% on commercial and institutional grounds, with larger plots (more than 1,000 sq m) also having planted or rewilded zones. The open space should not be paved to allow percolation. Compliance should be ensured by requiring project applicants to present site-level permeability plans, and final approval should be subject to verified implementation.
To assist with monitoring, remote sensing audits through drone-based and electronic GIS maps of plans can be used, and FAR incentives can be provided in the case of plots larger than the minimum OSR. This regulation will make a great contribution towards groundwater recharge, decrease the burden on stormwater facilities, and assist with biodiversity at the micro-urban level, both adding to the environment and urban sustainability.

7.1.3.3. PROMOTE PERMEABILITY

MANDATE PERMEABLE PAVEMENTS IN ZONAL REGULATIONS
MANDATE PERMEABLE PAVEMENTS IN ZONAL DRONS
Require sidewalks, driveways, and parking areas to use permeable paving materials such as porous concrete, interlocking pavers with sand grass pavers.
INTRODUCE MINIMUM OPEN SOIL AREA NORMS
Set a minimum percentage of open-to-sky soil area in resiential, commercial, and institutional plots, part of which includes planted or rewilded spaces
PROMOTE PERMEABILITY THROUGH BUILDING BYE-LAWS
Require permeable treatment of front yards, courtyards, and rooftops, and encourage permeable compoɾu wall designs

Figure 18 Permeable bye-laws

Chennai's present building bye-laws are largely concerned with the regulation of built-up area through FSI and setbacks but do not address how open and unbuilt spaces are handled, and thus these spaces get cemented. It leads to a missed opportunity for sustainable water management. The concept proposes amending building bye-laws in an overall manner to include permeability as a fundamental design requirement so that front yards, side yards, courtyards, rooftops, and other residual spaces promote infiltration. The bye-laws must be modified to require permeable surface finishes, such as pervious paving, gravel beds, green-covered rooftop cooling spaces, and rain gardens in inner courtyards. Pervious compound wall faces (such as jali or hollow blocks) can

enhance ventilation and water percolation. The bye-law must also encourage traditional Tamil Nadu architectural practices, such as percolation pits and rain-fed green spaces in courtyards. To facilitate adoption, these norms need to be incorporated in environmental clearances of large developments (over 5,000 sq.m) and connected with voluntary green building ratings such as IGBC and GRIHA with market incentives. Incorporating surface permeability in public and private development will help Chennai mitigate floods, enhance microclimatic conditions, and build the foundation for long-term sustainability of the urban built environment.

7.1.4. POLICY GUIDELINES FOR PALLIKARANAI MARSHLAND

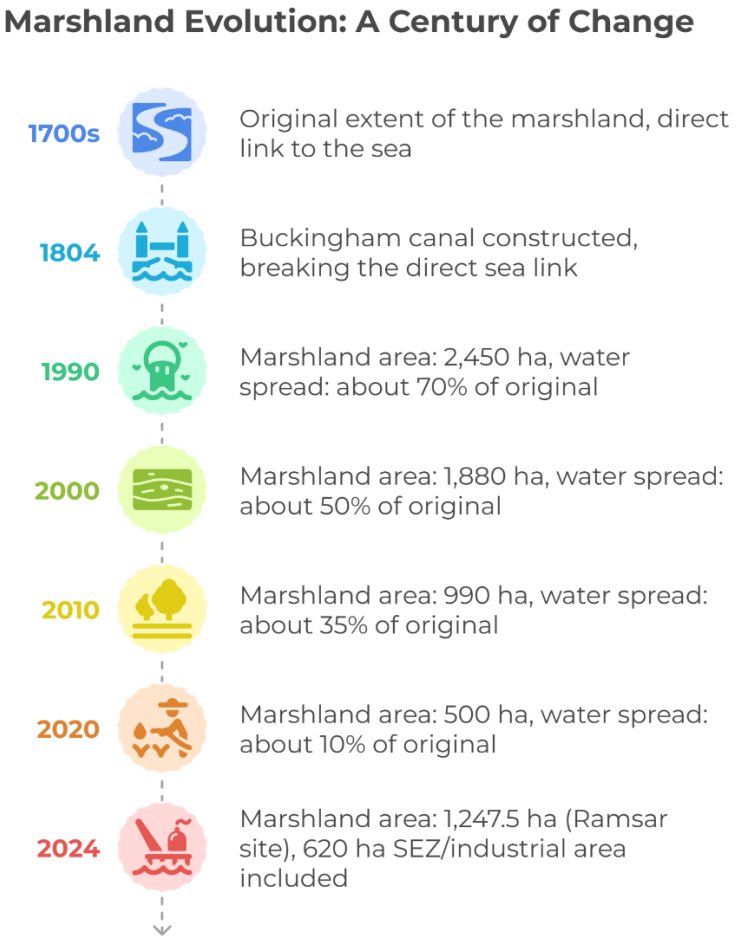
Marshland Evolution: A Century of Change
1700s
Original extent of the marshland, direct link to the sea
1804
Buckingham canal constructed, breaking the direct sea link
1990
Marshland area: 2,450 ha, water spread: about 70% of original
2000
Marshland area: 1,880 ha, water spread: about 50% of original
2010
Marshland area: 990 ha, water spread: about 35% of original
2020
Marshland area: 500 ha, water spread: about 10% of original
2024
Marshland area: 1,247.5 ha (Ramsar site), 620 ha SEZ/industrial area included

Figure 19 Marshland - Pallikaranai

The “Pallikaranai Marshland” in the southern Chennai is one of the city's last remaining natural wetlands and has enormous ecological and hydrological importance. In the past, the marshland had a direct connection with the Bay of Bengal and served as a natural flood buffer, a groundwater recharge area, and a biodiversity-rich habitat. Still, the last

two centuries have seen the marsh being largely degraded through human activities. The opening of the Buckingham Canal in 1804 was the first such major disturbance, cutting the marsh from the sea. By 1990, the marshland had already shrunk to 2,450 hectares and only occupied 70% of its original coverage. In the following decades, the rate of urbanization accelerated, and by the year 2020, the marsh had reduced to only 500 hectares, with just 10% of the initial water-spread area left. As of 2024, although 1,247.5 hectares have been assigned under Ramsar protection, almost 620 hectares of this territory consist of SEZs, highways, and institutional facilities, compromising the conserved status.

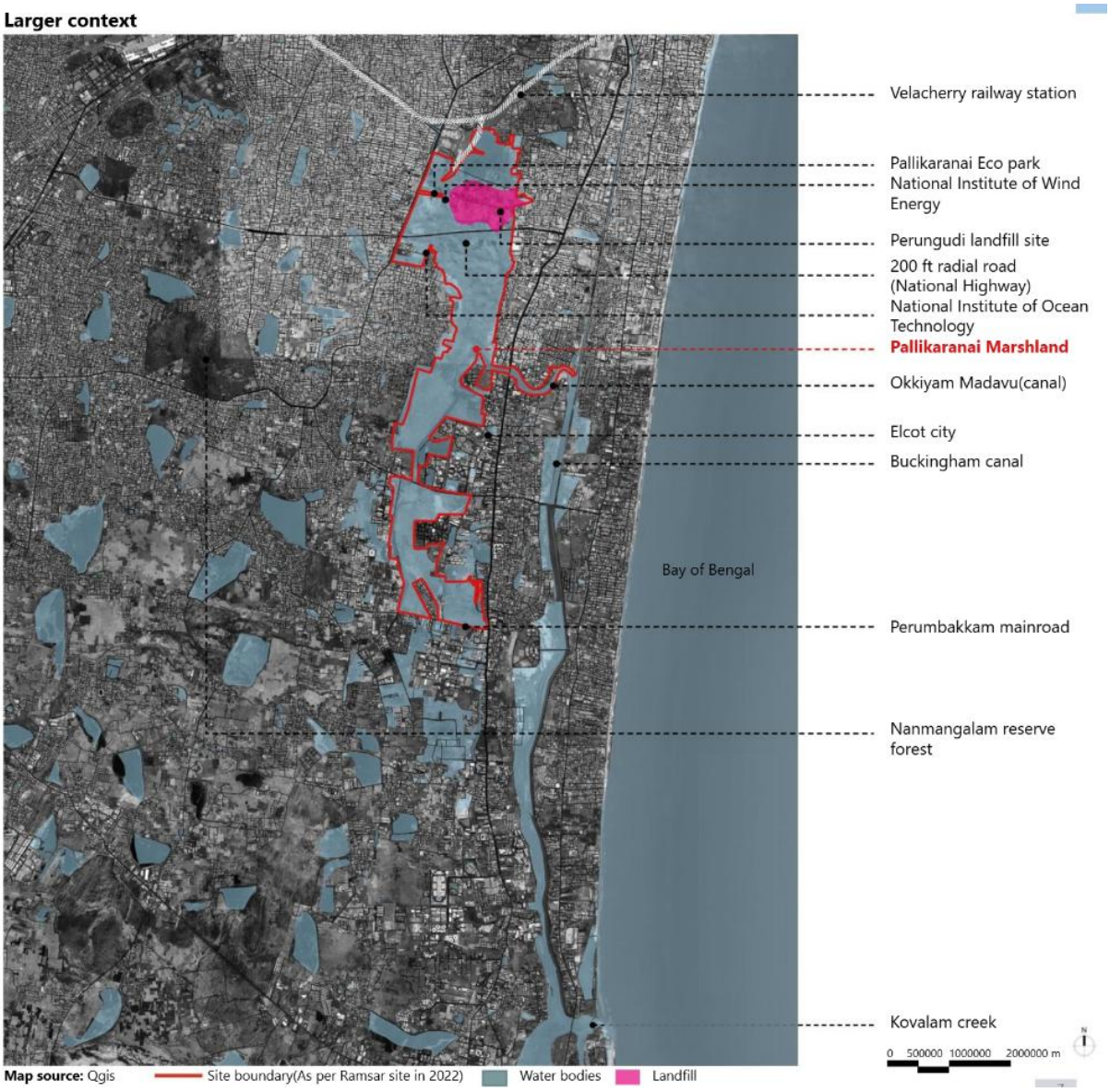

Figure 20 Outline of Existing marshland boundary

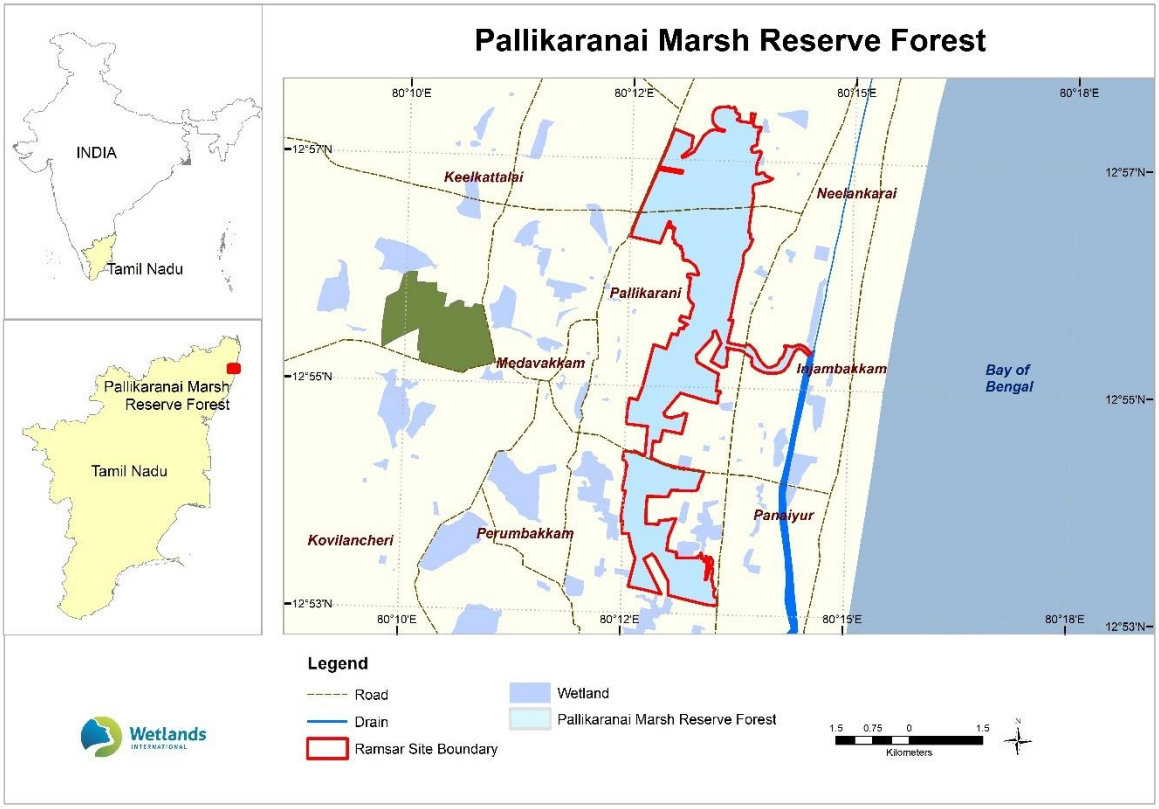

Figure 21 Marshland existing area

The marshland is now ringed with dense city-wide development in the form of residential colonies, broad roads, MRTS corridors, IT parks, and institutional campuses such as ELCOT City and National Institute of Ocean Technology. Hydrological connections of critical importance, like the Okkiyam Madavu canal and Buckingham Canal, have been blocked or constricted by haphazard development. The Perungudi landfill dump, lying beside the marsh, continues to contaminate toxic waste, and untreated sewage inflow from surrounding residential sites further lowers water quality. Visual maps and land use change statistics between 1990 and 2020 indicate a dangerous trend of natural wetland conversion to residential and industrial purposes. Fishing, dumping, grazing of cattle, and disposal of construction waste are prevalent, as indicated in the activity and sensory map of the area.One of the most critical concerns is the extremely fragmented and competing ownership of land in the marsh. The land is held by many stakeholders such as the Tamil Nadu Forest Department, Chennai Metropolitan Development Authority (CMDA), Tamil Nadu Housing Board (TNHB), ELCOT, MRTS, and private individuals. Even though it has been notified as a Ramsar site and reserve forest, extensive areas of land are still being utilized for incompatible uses like dumping, infrastructure development, and construction of housing. The absence of clear jurisdiction and lack of an integrated management authority resulted in weak enforcement of wetland regulations and persisting ecological degradation.A health evaluation by the Centre for

Environmental Studies, Anna University (October 2024) indicates the magnitude of degradation. The marsh is poorly ranked on nearly all ecological parameters. Over 6–10% of the wetland has been developed to non-wetland use since 2000.There is blockage or diversion of most natural inlets and outlets, and Biological Oxygen Demand (BOD) levels in water samples are above acceptable standards. Despite this decline, Pallikaranai Marshland continues to deliver vital ecosystem services. It supports provisioning (food, water, and wetland products), regulating (climate buffering, flood mitigation), supporting (soil and biodiversity maintenance), and cultural (recreational and spiritual) functions. However, these values are under constant threat from pollution, land encroachment, transportation corridors, industrial expansion, and climate variability. The site remains vulnerable to flooding, and its degradation amplifies urban disaster risks for Chennai's southern zones.

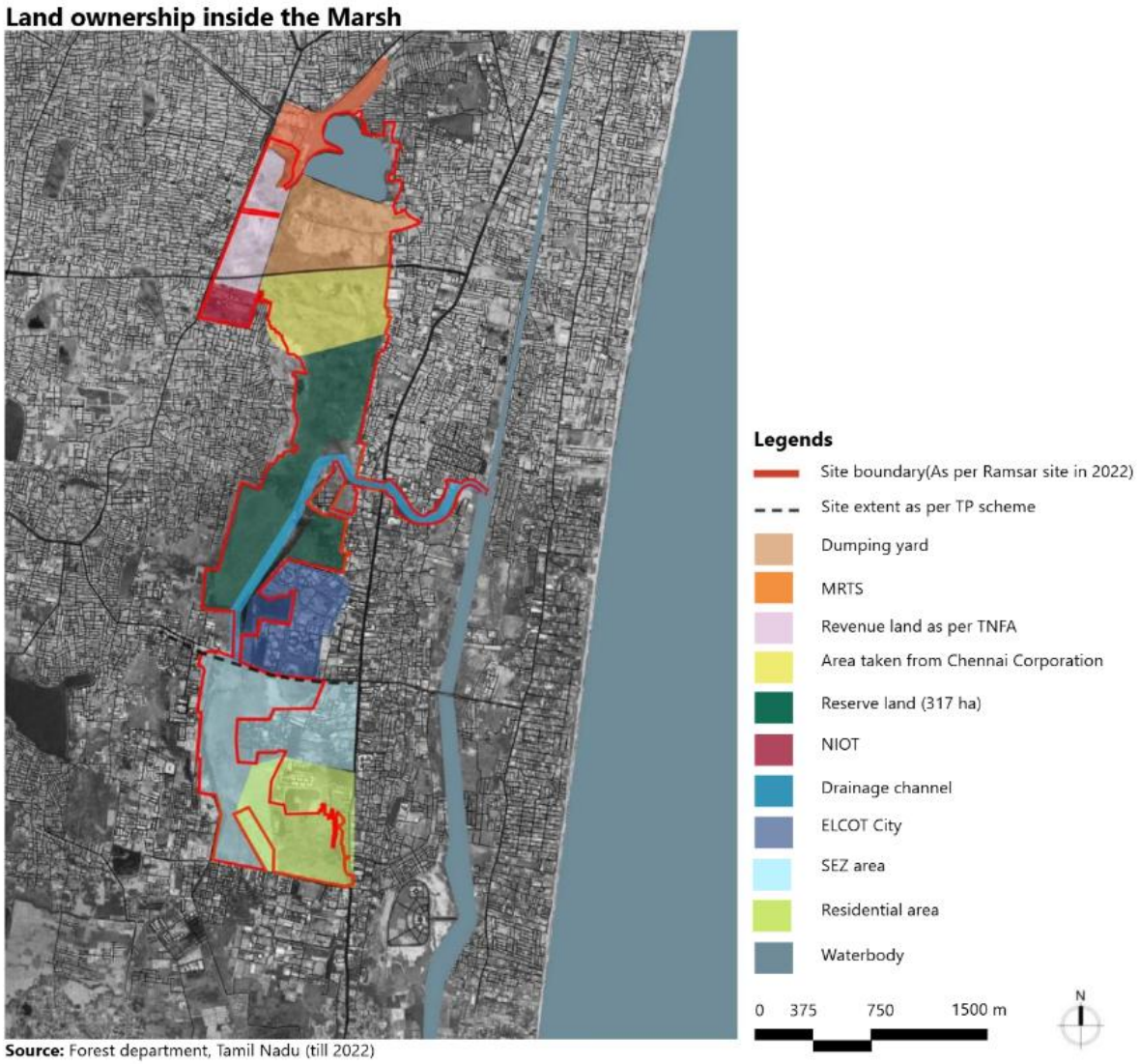

Figure 22 Land Ownership inside the Marshland

POLICY GUIDELINES:

Pallikaranai Marshland is one of the last natural wetlands in Chennai and was also notified as a Ramsar Wetland site of International Importance in 2022. The marshland has significant ecological functions such as flood management, recharging aquifers, and hosting a variety of species. Urbanization has led to a sudden reduction in marshland area, resulting in increased flooding and ecological loss. These guidelines aim to help local planning authorities (CMDA, municipal corporations, Tamil Nadu State Wetland Authority) manage land use, climate resilience, restoration, and conservation, drawing best practices from across states and national guidelines.

Buffer Zone and Land Use Zoning Regulations

"Mark Wetland and Buffer Zones:" Appropriate marking of the periphery of Pallikaranai along with a legally notified buffer zone (a minimum of 50–100 meters) with strict controls.

"Integrate into Urban Master Plan:" Declare the marsh and its buffer zone as a Conservation/Natural Zone within the Chennai Master Plan; ban incompatible land use and rezone incompatible zones.

"Ban Conversion and Development:" Ban conversion of wetland land into non-wetland purposes; allow only ecologically suited uses in the buffer. Enforce Kerala's Wetland Act and Maharashtra's High Court orders.

"Reference State Acts:" Kerala Conservation of Paddy Land and Wetland Act, 2008, and Maharashtra Wetland Conservation Mapping.

Prevention and Removal of Encroachment

"Survey and Notification:" Conduct detailed encroachment surveys, mark the legal limits, and utilize GIS/satellite/drone technology for surveillance.

"Enforcement:" Create a special enforcement cell; knock down illegal encroachments with due process and humane resettlement where necessary (as in Assam's Silsako Beel case).

"Legal Mechanisms:" Expedite legal cases, provide grievance redressal, and levy heavy penalties under environmental law.

"Relocation of Community:" Enact humane relocation and compensation of impacted vulnerable groups.

Climate-Resilient Infrastructure and Flood Mitigation

"Blue-Green Infrastructure Planning:" Declare the marsh as key blue-green infrastructure; connect to Chennai's drainage system and prevent natural channel closure.

"Ban Dumping:" Prohibit dumping of all construction waste; recycle and cap current landfills (e.g., Perungudi).

"Increase Flood Storage:" Construct storage ponds within the buffer; maintain drainage canals free of obstructions; retrofit the infrastructure to make it flood-proof.

"Flood Risk Zoning:" Label marsh and surroundings as High Flood Risk Zone;

require impact assessments on new developments.

Climate-Adaptive Ecological Restoration

"Restore Native Habitat:" Remove invasive species and replace them with native plants (consult ecological experts).

"Hydrological Restoration:" Restore water reservoirs and desilt water courses; implement adaptive management (gated outlets) for climatic fluctuation.

"Improve Water Quality:" Pre-treat sewage, develop artificial wetlands/ponds for treatment, pre-treat landfill leachate.

"Climate Habitat Design:" Design shallow/deep area mosaics; buffer trees planting; drought/flood resistance adaptation.

Monitoring and Community Involvement

"Establish Local Committee:" Establish a local wetland management committee comprising local community, NGOs, intellectuals, and officials (patterned after Kerala's local committees).

"Citizen Science:" Facilitate community monitoring (bird counts, water quality), sharing of data, and reporting infractions.

"Education & Awareness:" Support wetland education, signs, community events, and school curriculum inclusion.

"Livelihood Integration:" Encourage ecotourism at the community level, sustainable harvesting, and livelihood related to marsh conservation.

State/National Framework Alignment

"Compliance:" Maintain compliance with Wetlands (Conservation & Management) Rules, 2017 and Tamil Nadu State Wetland Authority action plans.

"Examples:" Use Kerala, Maharashtra, and Assam's successful wetland legislation and restoration programs as examples of best practices.

Pallikaranai Marshland is a valuable urban and ecological resource of Chennai. These guidelines provide a foundation to the effective regulation of land use, restoration, climate resilience, and joint conservation. Effective implementation will yield tangible dividends in flood protection, biodiversity, and for generations to come.

7.2. WAY FORWARD

The observe gives a complete flood danger estimation version this is tailor-made to the evolving city context of Chennai with the inclusion of danger, publicity, and vulnerability elements. While the version highlights inclined zones and gives essential drivers which include lack of inexperienced cover, low permeability, drainage deficit, and financial publicity very well, it additionally gives an possibility for destiny studies and action. In the destiny, possibilities exist to similarly increase the version via way of means of such as real-time hydrology information, weather projection, and

dynamic land use information to enhance predictability and responsiveness. Furthermore, the structure of the version is bendy and scalable and may be implemented to different metropolitan towns with comparable geographies, monsoon systems, or urbanization stresses to evaluate flood risk. Various parameter thresholds and spatial information permit the identical method to be implemented for different Indian towns and different areas of the globe for standardized, risk-primarily based totally city planning. More cooperation with companies which include CMDA, GCC, and TN-SDMA can combine it into improvement manipulate policies, zoning plans, and infrastructure improvement. Integration with citizens' participation, IoT sensor-primarily based totally drainage, and open information structures could make it extra responsive and inclusive. The course is to transform this analytical version right into a real-time decision-aid machine—a machine that publications policy, investment, and emergency control in instances of weather-pushed city flooding.

7.3. CONCLUSION

The observe gives a complete flood danger estimation version this is tailor-made to the evolving city context of Chennai with the inclusion of danger, publicity, and vulnerability elements. While the version highlights inclined zones and gives essential drivers which include lack of inexperienced cover, low permeability, drainage deficit, and financial publicity very well, it additionally gives an possibility for destiny studies and action. In the destiny, possibilities exist to similarly increase the version via way of means of such as real-time hydrology information, weather projection, and dynamic land use information to enhance predictaility and responsiveness.Furthermore, the structure of the version is bendy and scalable and may be implemented to different metropolitan towns with comparable geographies, monsoon systems, or urbanization stresses to evaluate flood risk. Various parameter thresholds and spatial information permit the identical method to be implemented for different Indian towns and different areas of the globe for standardized, risk-primarily based totally city planning.More cooperation with companies which include CMDA, GCC, and TN-SDMA can combine it into improvement manipulate policies, zoning plans, and infrastructure improvement. Integration with citizens' participation, IoT sensor-primarily based totally drainage, and open information structures could make it extra responsive and inclusive. The course is to transform this analytical version right into a real-time decision-aid machine—a machine that publications policy, investment, and emergency control in instances of weather-pushed city flooding.

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